

**THORACOLUMBAR SPINE FRACTURES:**  
**Diagnostic and Prognostic Parameters**

**F.C. Öner**



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**Front Cover: Frida Kahlo : The Broken Column, 1944**

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**THORACOLUMBAR SPINE FRACTURES:  
Diagnostic and Prognostic Parameters**

**THORACOLUMBALE WERVELFRACTUREN  
Diagnostische en Prognostische Parameters**

(met een samenvatting in het Nederlands)

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**door**

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### ABOUT LIFE

Life is no joke,  
you should take life very seriously,  
like a squirrel, for example,  
I mean, without expecting anything beyond and above life,  
all your task just being alive  
You should take life very seriously,  
so much, to such a degree,  
that, for example, with your hands tied behind, with your  
back against a wall,  
or, with your safety glasses  
and white coat in a lab,  
you should be able to die for others,  
even if you have never seen them before,  
even when no one forces you to do so,  
even though you know that the most valuable  
and the only real thing is life.  
I mean you must take life so seriously,  
that even at seventy, for example, you should plant olive  
trees,  
and not for the kids to inherit or whatever,  
but because you're afraid of death but don't  
believe in it  
but because life, I mean, weighs heavier.  
.....  
This earth will cool off,  
a tiny star among many,  
and one of the smallest, too.  
I mean, just a gilded mote on blue velvet,  
this huge world of ours.  
This earth will cool off one day,  
not like a block of ice  
nor even like a lifeless piece of cloud  
but like an empty walnut  
this earth will fall into the abyss, boundless and dark...  
You should feel the pain of this right now,  
feel the sorrow already.  
You should love this world, I mean, so much  
to be able to say "I have lived"

**Nazim Hikmet (1947)**







This thesis is based on the following articles, which have appeared or will appear as separate publications:

**Speth MJGM, Oner FC, Kadic MAC, de Klerk LWL, Verbout AJ:** Recurrent kyphosis after posterior stabilization of thoracolumbar fractures. *Acta Orth Scan* 1995; 66(5):406-410.

**Verbout AJ en Oner FC:** Wervelletsels; vroeger en nu. *Ned. Tijds Orth* 1998; 5:21-32.

**Verbout AJ en Oner FC:** Thoracale en lumbale wervelletsels met neurologische uitval. In "Handboek dwarslaesie revalidatie", Editor FWA van Asbeck, Bohn Stafleu Van Loghum, Houten, 1998:28-43.

**Oner FC, vd Rijt RHH, Ramos LMP, Dhert WJA, Verbout AJ:** Changes in the disc space after thoracolumbar spine fractures. *J Bone Joint Surg* 1998; 80-B:833-839.

**Oner FC, vd Rijt RHH, Ramos LMP, Groen GJ, Dhert WJA, Verbout AJ:** Correlation of MR images of disc injuries with anatomic sections in experimental thoracolumbar spine fractures. *Eur Spine J* 1999; 8:194-198.

**Oner FC, van Gils APG, Dhert WJA, Verbout AJ:** MRI findings of thoracolumbar spine fractures. A Categorisation based on MRI examinations of 100 fractures. *Skel Radiol* 1999; 28:433-443.

**Oner FC, Ramos LMP, Simmermacher RKJ, Kingma PTD, Diekerhof CH, Verbout AJ:** AO classification of spinal fractures: problems of reproducibility. *Spine* (submitted, *Spine*, under revision).

**Oner FC, Faber JAJ, Dhert WJA, Verbout AJ:** Prognostic significance of MRI findings of the fractures of the thoracolumbar spine. A prospective study of 53 patients with 71 fractures. (Submitted).









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## INTRODUCTION AND AIMS OF THE STUDY

Fractures of the thoracolumbar spine with or without neurological deficit continue to be an area of major interest in traumatology. Although less common than traumatic injuries of the extremities, spinal injuries have the lowest functional outcomes and the lowest rates of return to work after injury of all major organ systems (Hu 1996). The biomechanics of injury patterns and the evaluation of treatment methods have been the subject of intensive research activity during the last two decades. New treatment methods have been introduced, evaluated and led to passionate discussions in the literature. Although some bad practices such as laminectomy operation without stabilization of the spine were abandoned as a result of this research and education activity, a real consensus about the appropriate treatment of the majority of the injuries has not yet been achieved. In general, the treatment of these fractures changed dramatically over the past two decades. Newer and more aggressive methods of surgical care have gained popularity. Rapid developments in spinal surgery have changed the older ideas and expectations about the outcomes of spinal fractures. The fatalistic mentality of the older generations, which accepted as very good results almost 60% of patients experiencing significant pain after a recumbence of minimal 3 months (Nicol 1949) has been questioned. The availability of safe and effective surgical stabilization became an attractive alternative for many patients who would otherwise be confined to bed for months with a prospect of significant residual deformity and pain. However, the less invasive and apparently cheaper methods of conservative management remain a viable alternative for the majority of the patients.

If there is choice, there is confusion! The problem of what to do and when to do it continues to create heated controversy. The difficulty begins with the scarcity of reliable prognostic parameters. Thoracolumbar spine fractures are complex injuries of a compound organ with distinct parts of different susceptibility to injury and different healing potentials. Injury to such a complex biological system is the beginning of a chaotic process the outcome of which is per definition highly unpredictable. If one does not have the means of altering the outcome of such a process anyway, one does not need to bother;





no meteorologist would experience sleepless nights about the question of whether or not it will rain over two weeks. But making decisions that would effect the outcome of a process brings responsibility. And for a sound decision in such a case, one needs evidence-based prognostic criteria. Prognosis means seeing into the future. "The purpose of brains is to create futures" (Dennet 1996). To see into the future begins with seeing the present and relating the present with the patterns recognized in the past.

Therefore, the aim of this study is to search for the reasons for the difficulties encountered in the diagnosis and for the choice of proper treatment of these injuries as well as to develop new ways of investigation using the magnetic resonance imaging techniques. The existing schemes are critically analyzed and the possibilities of refinement of these schemes with the new imaging technique of MRI are explored. The reliability of the MRI concerning some of the structures involved is tested in a cadaver study. The MRI findings are categorized in a large enough sample of clinical cases. The problems associated with posterior stabilization techniques are investigated. The changes in the intervertebral disc space after fractures are studied with the MRI. Finally the prognostic significance of all these findings is investigated in a prospective study of a cohort of patients with thoracolumbar spine fractures.





**EPIDEMIOLOGY AND A SHORT HISTORY  
OF THE FRACTURES OF THE  
THORACOLUMBAR SPINE**



**CHAPTER 1**

## 1.1 EPIDEMIOLOGY OF SPINE FRACTURES

There is strong evidence that the incidence of vertebral fractures is increasing in the industrialized world in the second half of the 20<sup>th</sup> century. Few reliable statistics are available about the exact incidence of all vertebral injuries. According to one epidemiological study in 1977 limited to four major hospitals in Sacramento County, California, the estimated annual rate of occurrence resulting in hospitalization was 233 per million population (Donchin 1993). In Israel this figure is estimated to be around 350 per million population. In a complete population-based study using the Manitoba Health Services Insurance plan, Hu et al (1996) found an average annual incidence of 64 per 100,000 with an annual hospitalization rate of 29 per 100,000 in Manitoba, Canada. This figure includes all spinal fractures including pathological conditions such as osteoporosis. In the 15- to 19-year-old age group the rate of new spinal fractures was 86 per 100,000 and for the 20- to 29-year-old age group 88 per 100,000, which gives a better indication of the incidence of traumatic injuries.

In the Netherlands, according to the data provided by SIG, between 1987 and 1991 a yearly average of 2 254 admissions were registered with the main diagnosis of a fracture of the thoracic or lumbar spine. This gives an annual incidence of 150 per million. This low incidence may be misleading because the majority of these patients have multiple lesions and may accordingly have been registered under a different major injury.

According to an international survey, out of 1 019 patients 66.8% were men and 33.2% were women (Gertzbein 1992). The average age was 31.7 years (11-88). According to the same survey 51% of the fractures were the result of motor vehicle accidents, 34% result of a fall, 5% work-related, 2% occurring in the home and 8% caused by other mechanisms. In this group there were 389 associated non-skeletal injuries and 362 skeletal injuries.

Neurologic damage is a common complication of thoracolumbal vertebral fractures. In the same survey of the Scoliosis Research Society, according to the Frankel classification, 19% of the patients were Grade A, 2% Grade B, 7% Grade C, 17% Grade D, and 55% Grade E. In another study, rates of traumatic spinal cord injury in Olmsted County, Minnesota, were found to have increased steadily in







the 47 years period from 1935 to 1981 from an average of 22.2 in the period from 1935 to 1944 to 70.8 per million person-years for the years 1975 to 1981 (Donchin 1993). In a more recent survey of the AO group, the overall incidence of neurological deficit in 1212 patients was found to be 22% (Magerl 1994).

## 1.2 A SHORT HISTORY OF THE DIAGNOSIS AND TREATMENT OF THORACOLUMBAR SPINE FRACTURES

“ Bei der wichtigen Rolle, welche die Wirbelsäule in der Ökonomie des Körpers spielt, gehört eine Verletzung derselben zu den schwersten, welchen der menschliche Leib überhaupt ausgesetzt ist.”

Gurlt 1860

### 1.2.1 ANTIQUITY

The first written record of the diagnosis and treatment of spinal injuries is found in the Edwin Smith Surgical Papyrus. This papyrus is said to be a seventeenth century BC copy of an original manuscript which probably dated from about 3000 BC (Breasted 1930). In the Breasted translation there are some descriptions of cases with spinal injuries most of which concerning paraplegia as a result of cervical injuries such as:

“**Case 31.** Dislocation of a cervical vertebra

**Examination:** If thou examinest a man having a dislocation in a vertebra of his neck, shouldst thou find him unconscious of his two arms (and) his two legs on account of it, while his phallus is erected on account of it, (and) urine drops from his member without his knowing it; his flesh has received wind; his two eyes are blood-shot; it is a dislocation of a vertebra of his neck extending to his backbone which caused of him to be unconscious of his two arms (and) his two legs. If, however, the middle vertebra of his neck is dislocated, it is an emissio seminis, which befalls his phallus.

**Diagnosis:** Thou shouldst say concerning him: “One having a dislocation in a vertebra of his neck, while he is unconscious of his two arms (and) his two legs and his urine dribbles. An ailment not to be treated.”

The only case of a thoracolumbar injury is unfortunately incomplete:



**“Case 48. A sprain in a spinal vertebra:**

**Examination:** If thou examinest (a man having) a sprain in a vertebra of his spinal column, thou shouldst say to him: “Extend now thy two legs (and) contract them both (again).” When he extends them both he contracts them both immediately because of the pain he causes in the vertebra of his spinal column in which he suffers.

**Diagnosis:** Thou shouldst say concerning him: “One having a sprain in a vertebra of his spinal column. An ailment which I will treat.”

**Treatment:** Thou shouldst place him prostrate on his back; thou shouldst make for him...”

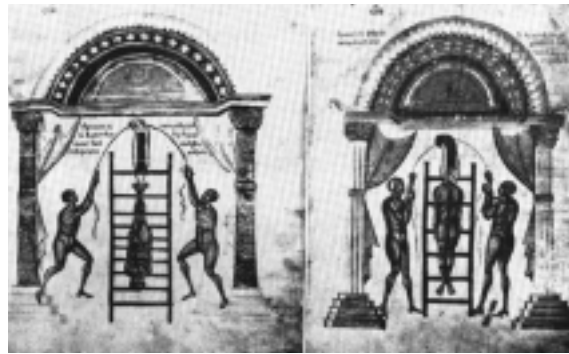
There are no other written records about spinal injuries between these ancient Egyptian descriptions and the writings attributed to Hippocrates (460 - 377 BC). In the Corpus Hippocraticum, in the chapter “On Articulations” spinal injuries are treated. In this oldest known description of manipulative reduction, Hippocrates describes two methods. The first one is a procedure known as “shaking on a ladder” in which the patient is wrapped up over a ladder head down and the ladder is let go from a tower or the mast of a ship. Hippocrates is very skeptical about this procedure:

“ Shaking on a ladder has never straightened anybody as far as I know, but it is principally practiced by those physicians who seek to astonish the mob... The physicians who follow such practices, as far as I have known them, are all stupid.”

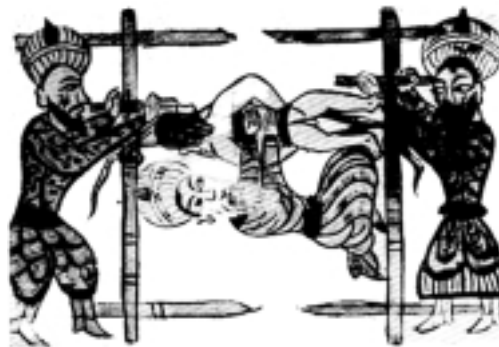
This is probably the first written controversy in matters of spinal surgery, but definitely not the last! Despite these negative remarks this procedure was probably used for a very long time by the practitioners of Hippocratic medicine. In the Niketas collection of Greek manuscripts that were gathered at the request of the Byzantine Emperor Constantine in the eleventh century AD there are two illustrations of this procedure (Fig. 1.1).

Hippocrates preferred various methods of traction and direct manipulation. He described a bench on which the patient would lie down face downward. Traction would be applied through a leather piece wrapped around the chest and the shoulders and another leather band applied above the knees and the ankles. In this way pressure could be applied to the gibbus under traction which, according to Hippocrates was very safe (Fig. 1.2). He also reports an unsuccessful





**Figure 1.1:**  
*The reduction technique of 'shaking on a ladder'. From Niketas collection.*



**Figure 1.2:**  
*Turkish miniature showing reduction of the spine using Hippocratic technique.*

experiment with a pig bladder, which he used to treat a fracture with hyperextension.

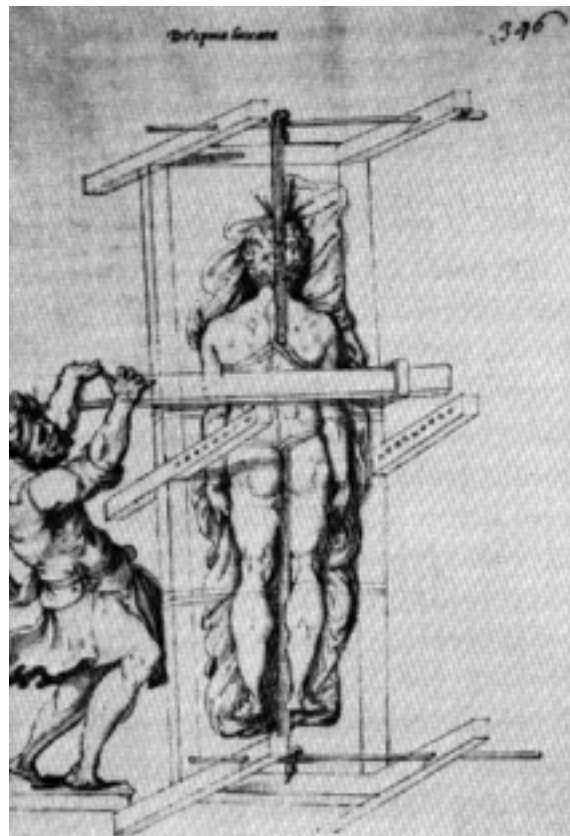
Hippocrates believed that dislocations forward were necessarily fatal and that the spinal cord could stand a circular but not an angular distortion. It remains a mystery what he meant by that.

Oribasius (325-400 BC) further developed the Hippocrates' bench by adding to one side of the bench an iron attachment in which a plank could be inserted to be used as a lever for reduction of the fracture (Fig. 1.3).

The first operative intervention in spinal injury was described by Paulus Aeginata (625-690 AD). In the Book VI, the surgical part of his compendium, he said that when there is a fracture of the spinal



**Figure 1.3:**  
*Hippocratic bench*  
after Oribasius.



column with compression of the cord, an incision should be made above the injury and that the piece of bone compressing the cord should be removed. He also advised removal of a fractured spinous process if it was causing pain. He, unfortunately, did not describe the results of his operation but warned the readers of the dangers of this procedure (Adams 1846).

In the great book of early Hindu medicine, the Sushruta Samhita, immobilization methods with a board and ropes with five pegs were described. On the whole the Sushruta was very pessimistic about the prognosis of fractures of the spine (Howorth 1964).





**Figure 1.4:**  
*Ibn Sina (Avicenna)*  
reducing a dislocation.

### 1.2.2 THE MIDDLE AGES AND THE RENAISSANCE

During the Middle Ages, the Islamic surgeons continued the Hippocratic tradition. The writings of Ibn Sina (known as Avicenna in Latin) (980-1037) (Fig 1.4) and Abu al-Qasim (known as Albucasis in Latin) (936-1013) were standard textbooks during this period in the Mediterranean world. They both described methods for reduction of the fractured spine similar to the methods of Hippocrates and Paulus Aeginata but did not mention any operative intervention for removal of compressing bone because both of them believed that fractures of the vertebrae were fatal if accompanied by neurologic involvement.

In the Renaissance period, the famous surgeon Ambroise Paré, in his 1564 book “Dix Livres de Chirurgie” revived Paulus Aeginata’s operative approach in case of fractures producing cord compression. He also described a procedure, which is probably the first attempt to posterior fusion. He said that the pieces of the lamina should be put back in their original position, splinted, and allowed to reunite. He advised immobilization of all spinal fractures by splints or lead plates and keeping the patient for a long time on his back.

In the seventeenth century, Fabricius von Hilden, the father of the German surgery, was very bold and adventurous in his approach to spinal injuries. If traction and manipulation failed in the what he called inward dislocations, he proposed a new operative approach in which the spinal process would be prepared, seized with forceps and pulled back to its place.



### 1.2.3 RENAISSANCE TO 20TH CENTURY

Paul Barbette is probably the first Dutch surgeon who wrote about spine fractures (Barbette 1663, first edition 1647). He popularized Paré's methods in the northern countries. Paul Barbette was one of the most famous surgeons and anatomists of the 17<sup>th</sup> century Amsterdam. As an introduction to one of his books the famous Dutch poet of the time J.V. Vondel called him "den Duitsche Hippokraet" (see frame).

His surgical and anatomical works were published in Latin and Dutch and were translated to English and German (Barbette 1663, 1672, 1672). His English translator praised his work as "Composed according to the Doctrine of the Circulation of the Blood, and other new Inventions of the Moderns" (Barbette 1672, English translation). His works were considered "state of the art" during the second half of the 17<sup>th</sup> century. In the original 1663 Dutch text, the following passages concerning the spinal injuries are found:

#### *CAP. IV: van de besondere Beenbreucken*

....

*8. Een enkele fracture der wervelbeenen wordt met de vingeren seer lichtelijk ingefet, en geneest in 20 dage. Maer wordt het ruggemargh soodanigh gequetst of ingedruckt, dat des patients armen oft beenen lam en ongevoeligh worden, dat hij niet pissen, noch den kamer-gang naer believen uytstellen kan, soo blyft de dood seer selden uyt. Doet niettemin het uysterste, en is 'er een of meer beentjes t'eenemael van 't periostium los, soo maeckt een opening, en neemt haer uyt.*

....

#### *CAP. VI: van de besondere Ontledingen*

....

*5. Als de wervelbeenderen des ruggen uytwaerts wycken, soo moet men de patient op de buyck leggen; hem door twee dienaers en twee banden, d' een onder d' oxelen, d' ander om de heupe gebonden, styf laeten uyt-recken, en alsoo het wervelbeen indringen. Als sy innewaerts ontleeden, soo is het doodelijck.*

....



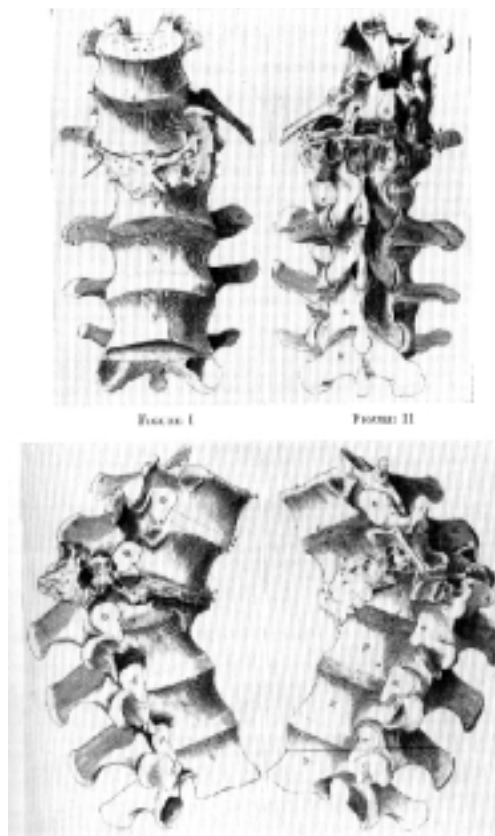
**Op de Heelkunst van Dr. Paulus Barbette:**

Hier verschynt een heelzame Paulus,  
Niet gelyck een wrede Saulus,  
Die met scherpe klauwen grypt,  
En de tanden wet en slypt  
Op doortrapte en helsche vonden  
Van geweer, om volck te wonden,  
Ter vernielen, en verwoet  
Zich te baen in menschenbloet,  
En den vetten buit te deelen;  
Maer hy komt gewonden heelen,  
En genezen, door de gunst  
van zijn meesterlijke kunst.  
Hulpeloozen, gaetghe quynen,  
Dol van weedommen en pynen,  
Aen gekrompen aêr en zeên,  
Aen een breuck van arm en been,  
Of gekneusde ledemaeten;  
Legtghe in 't uiterste verlaeten,  
Door een diepe vleesquetzuur;  
Schynt de geest, van uur tot uur,  
't Zwacke lichaem te begeven;  
Kan 't veraerde bloet het leven  
Niet bewaeren; loopt om raet  
By den Duitschen Hippokraet,  
By Barbette, die zijn zegen  
Uitgiet over den verlegen,  
En den bant breeckt, die zoo stout  
De natuur geknevelt houdt.  
Zijne Heelkunst ongedwongen  
Komt ter zijden uitgesprongen.  
Uit de volle Medicyn,  
Als een ader uit den Rijn,  
En verquickt de dorre leden,  
In de Zeestadt aller steden,  
Dies zy hem deze eere geeft  
Dat hy voor een ander leeft.

**J.V. Vondel, Amsterdam (in Barbette 1663)**



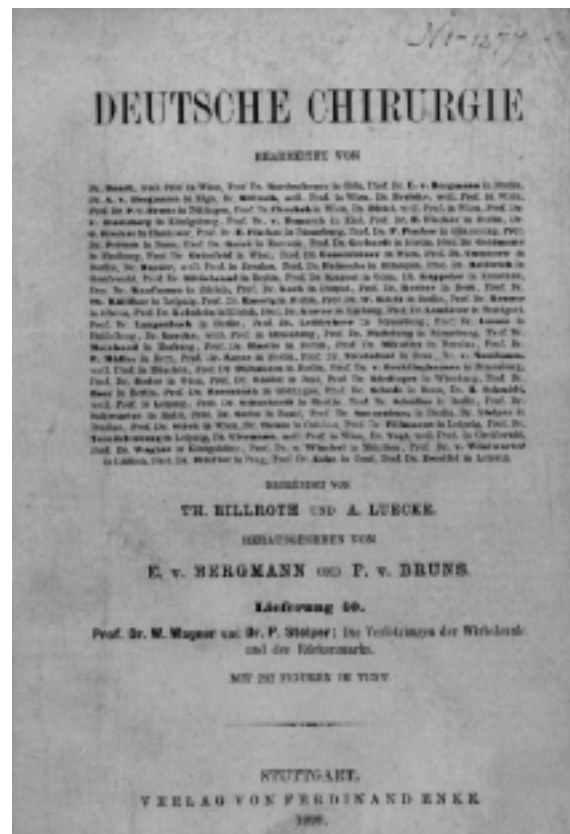
**Figure 1.5:**  
Copper plate showing  
the pathoanatomy of a  
healed fracture-  
dislocation (From  
Sömmering 1793).



This “modern” 17<sup>th</sup> century surgeon actually repeated the conviction of Hippocrates that inward dislocations would always be fatal. 18<sup>th</sup> century saw the first controversies about surgical decompression and the first scientific interest in the patho-anatomy of traumatic spinal injuries. Chopart and Desault (1797) suggested trephining between the vertebrae for decompression of the spinal canal, but they did not mention the results of this procedure. The first detailed description of a case history, complete with a precise description of the pathological changes obtained by the autopsy of the patient 6 months after the injury, came from Germany in 1793 (Sömmering). This excellent description has been completely translated and repro-







**Figure 1.6:**  
Special edition of  
"Deutsche Chirurgie"  
about spine fractures  
by Wagner and  
Stolper (1898).

duced in Howorth (1964). The marvelous copper plate illustrations of a healed fracture-dislocation of the first lumbar vertebra are the first detailed pathologic specimens in the literature (Fig. 1.5).

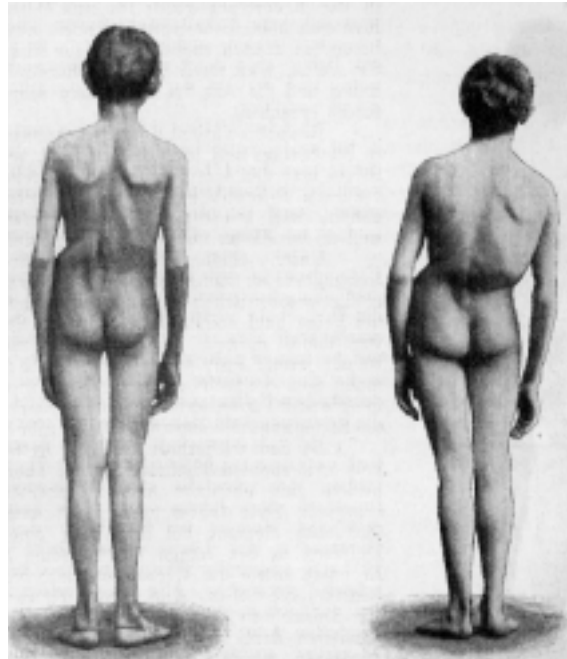
During the whole nineteenth century, spinal injury was a "hot item" among the most prominent surgeons and neurologists of the world. In the extensive literature list of a German monograph about spinal injuries at the end of the century, one can find the names of almost every known surgeon and neurologist of the century (Wagner 1898) (Fig. 1.6). A major issue was the laminectomy operation. In England a serious controversy emerged between the supporters and opponents of laminectomy after the debate between the two best known surgeons



of the time Sir Astley Cooper and Sir Charles Bell. The first laminectomy in the modern era was performed in 1814 by the London surgeon Henry Cline. Although the first reported results were disastrous, Cooper believed that this operation could be valuable if the technique was improved. This caused a famous quarrel with Bell who said that a man would have to be already dead if he were not injured by this operation (Howorth 1964). Throughout the nineteenth century in England and the United States this operation has been reported with varying results. Although Brown-Séguard (1856) showed experimentally on guinea pigs that early decompression could reverse paraplegia, the French and German surgeons were very reluctant about this operation. Lisfranc (1843) only mentioned that such an operation had been reported by some English surgeons. Hoffa, (1896) who never did the operation, was nevertheless hopeful about the recent improvements. Wagner and Stolper (1898) described the procedure and its variants but concluded that there was very limited indication for the procedure only in case of paraplegia caused by an isolated lamina fracture or by a gunshot or stab wound. At the end of the century, however, it was a French surgeon, Chipault who vehemently propagated laminectomy (Chipault 1890, 1892). In the French literature, this operation was called the “Chipault procedure” until 1960’s.

Conservative treatment of the thoracolumbar spine fractures, on the other hand, was refined and sound practices were established in the nineteenth century. Malgaigne (1847), who was also an expert in Hippocratic writings, reintroduced reduction by hyperextension. He described reduction techniques through extension and direct pressure on the fractured segment with pillows and sheets. He actually repeated the technique, which was unsuccessfully tried by Hippocrates using a pig bladder. In Germany, Hoffa (1896) popularized this method. Hoffa described reduction in hyperextension in a Rauchfuss suspension sling. Reduction in hyperextension became the standard technique in the first half of the twentieth century through the works of Böhler (1929) and Watson-Jones (1931, 1938). In the second half of the nineteenth century, immobilization techniques were also developed. The “goutière” or the gutter splint, propagated by Bonnet (1860) of Paris was the most popular. This gutter splint extended along the back from cervical spine to the pelvis, splinting the spine





**Figure 1.7:**  
*Progression of  
deformity after a  
'minor' fracture.  
(Wagner 1898)*

from two sides and thus completely immobilizing it. The patient lay in this splint until the physician decided that the back was healed. Plaster jacket also became very popular in this time after its successes in the treatment of Pott's disease (spinal tuberculosis) reported by Sayre (1878). Many physicians used plaster jacket for immobilization after reduction of the fracture in the old way. Wagner and Stolper called attention to the fact that some seemingly innocent, minor injuries of the spine could progress to serious deformity (Figs. 1.7, 1.8). They recommended plaster jacket treatment for this kind of injuries.

The last decade of the nineteenth century witnessed a milestone in the diagnosis and treatment of spinal fractures. The "X-rays" developed by Röntgen (1895) revolutionized the diagnosis of spinal disorders. Within three years after the invention of x-rays, the first 'x-rays pictures' of cervical, thoracic and lumbar spine (Fig. 1.9) appeared in the literature coincidentally in a special edition of 'Deutsche



**Figure 1.8:**  
*Post-traumatic  
kyphosis.*  
(Wagner 1898)



Chirurgie” about spinal fractures (Wagner 1898). These authors also reported the first successful imaging of an injured spine:

“ .. Herr Professor Oberst in Halle, einer der verdienstlichsten Förderer dieser neuen Untersuchungsmethode, schreibt uns, dass er den Sitz von Fracturen auf der photographischen Platte gewöhnlich ganz gut habe sehen können, und dass es ihm zweimal gelungen sei, eine Dislocation mit Zerreissung der Bandscheibe zu erkennen, wo man einen Wirbelkörperbruch annehmen zu müssen glaubte. Die Obduction bestätigte beide Mal das Ergebniss der Röntgenuntersuchung.”

Before the invention of the X-rays, only injuries with gross deformity could be recognized as a (fracture-) dislocation. In Kocher’s 1896 series, 90% of the patients with vertebral fractures had neurologic injury (Wagner 1898). Many of the fractures of the thoracolumbar spine were called contusions or distortions of the spine for lack of means of detection. Detection of different fracture and dislocation patterns led to the first attempts to classification of these injuries.

#### 1.2.4 20TH CENTURY

##### 1.2.4.1 ADVANCES IN CONSERVATIVE TREATMENT

Conservative treatment of the thoracolumbar spine fractures with the techniques developed and refined in the nineteenth century became the standard treatment in the first half of the twentieth century. The massive scale of injuries during the first world war, unprecedented in the history of mankind, gave the surgeons of all the belliger-





**Figure 1.9:**

*The first 'x-ray pictures' of the spine.*

*(Wagner 1898).*

*Exposure time was mentioned only for the cervical spine:*

*12 minutes!*

ent countries the impulse to standardize treatment regiments and to emphasize measurements to rehabilitate the injured patients so that they could be sent back to the front as quickly as possible. Lorenz Böhler, who was later during the second world war “beratender Chirurg einer Armee im Felde” and dedicated the “9. -11. umgearbeitete und vermehrte Auflage” of his famous book “Techniek der Knochenbruchbehandlung” to “dem Wehrmachts-Sanitätsinspekteur Generaloberstabsarzt Professor Dr. Handloser” was exemplary of this militarized, almost industrial approach (Böhler 1929, 1930, 1943). His approach was based on the following assumptions:

- The same kind of lesions take the same time for healing (temporal standardization)
- Invalidity is proportional to residual deformity (standardization of manipulation)
- Specific exercise is necessary for the prevention of muscle waste and facet joint arthrosis (standardization of exercise treatment).

He summarized the standard treatment as:

- Einrichten
- Festhalten
- Üben

Reduction was achieved by gradual hyperextension (Fig. 1.10), as soon as possible after the fracture but in any case within the first three weeks. After the confirmation of reduction with radiograms, a plaster of Paris jacket was applied (Fig. 1.11). A good reduction was essential:

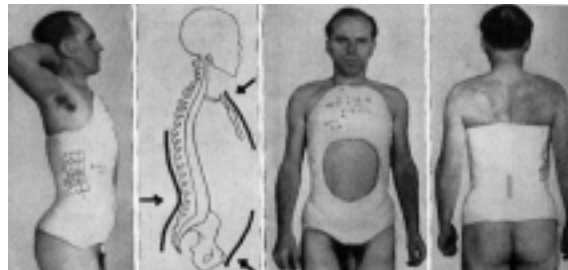
“Es Muß hier mit allem Nachdruck festgestellt werden, daß ohne Einrichtung jeder feste Verband nicht nur überflüssig, sondern schädlich ist”.



**Figure 1.10:**  
*Böhler's method:*  
 1- Einrichten.



**Figure 1.11:**  
*Böhler's method:*  
 2- Festhalten.



**Figure 1.12:**  
*Böhler's method:*  
 3- Üben.



From the first days after the reduction and immobilization a standardized training program was started to avoid muscle loss and facet joint arthrosis (Fig. 1.12). Böhler also emphasized the important psychological effects of a training program:





“ Das Einrichten und Festhalten sind technisch-mechanische Probleme. Weil man die Verletzten damit schmerzfrei macht, kann man schon in den ersten Tagen mit einer entsprechenden Übungsbehandlung beginnen. Damit gibt man den Verletzten nicht nur Muskelkraft und Gelenkigkeit, sondern auch Selbstvertrauen und Freude und beeinflußt nicht nur den Körper, sondern auch die Seele in günstiger Weise (Psychotherapie)”.

The duration of plaster jacket treatment was also standardized:

- for fractures with less than 5° of kyphosis 8-10 weeks;
- for fractures with a kyphosis angle between 5-15° 12 weeks;
- for fractures with a kyphosis angle between 15-20° four months;
- and for fractures with a kyphosis angle of more than 20° five months.

With this standardized treatment regime, Böhler was not only the founder of modern functional conservative treatment but also of the influential German school which later, with technical innovations, changed to an operative solution of the “technisch-mechanische Probleme” of good reduction and immobilization but at the same time it kept the emphasis on achieving a rapid ambulation of the patient in order to reduce morbidity.

Böhler’s book was rapidly translated into English (1. edition 1929, 2. edition 1930, 3. edition 1932, 4. edition 1935) and was influential in the approaches of Watson-Jones (1931, 1938) who popularized Böhler’s ideas. The teaching of Böhler echoed in the following words of this most influential British trauma surgeon of the time:

“ Perfect recovery is possible only if perfect reduction is insisted upon; even slight degrees of wedging of the vertebrae may cause persistent aching pain” (Watson-Jones 1943).

However, it was soon recognized that deformity quite often recurred after this rigorous treatment (Stanger 1947), and was not necessarily related to the clinical outcome (Nicoll 1949). Nicoll, based on his observations as a consultant surgeon of the special rehabilitation centers of the miners of Great Britain, questioned the orthodoxy of Böhler / Watson-Jones line. In his 1949 article he concluded that:

- a good functional result is *not* dependent on a good anatomical result;



- consolidation is rapid even in the absence of fixation;
- the important factor in determining function is stability between the damaged segments and not the position in which it is achieved;
- prolonged fixation of damaged soft tissues, especially in their shortened (lordotic) position, is in itself a cause of disability.

Nicoll reported that 89/152 of his patients still had substantial pain. 40% of these had pain at site of fracture and 60% low back pain. Nevertheless Nicoll, with his extensive study of 152 miners with thoracolumbar fractures, established an alternative orthodoxy, which to a great extent determined the thinking in English speaking countries from the post-war era to this day. In the modern controversy between the proponents of a conservative vs. operative approach his line evolved into the position defended by Mumford and Weinstein (1993/a, b) in the Anglo-Saxon world and by van Linge in the Netherlands (Klerk 1993).

Holdsworth (1963), although following the line of Nicoll, was not really sure of the good outcome of all injury types. He emphasized that “unstable” fractures or fracture dislocations with a significant discoligamentary injury should better be treated by open reduction and fusion.

Although conservative treatment became a good established treatment modality in the twentieth century, no agreement has been achieved as to the duration of bed rest or immobilization in a plaster jacket. Böhler (1943) confessed in the 9. edition of his book that he had previously advised 6-12 weeks of immobilization because he was intimidated by the critics who pointed to the deleterious effects of long immobilization on the spine:

“ Vor 1934 habe ich nur eine Fuhigstellung von 6-12 Wochen angegeben, weil ich noch nicht genügend Erfahrung hatte und weil ich von den Kampfkrufen jener etwas eingeschüchtert war, welche auf Grund von theoretischen Erwägungen immer wieder behaupten, daß jeder feste Verband an der Wirbelsäule Versteifungen und Muskelschwund erzeuge”.

Nicoll recommended for his “functional treatment” of stable fractures three to four weeks of bed rest! For the “unstable” fractures he advised “protective plaster” in the neutral position until spontaneous





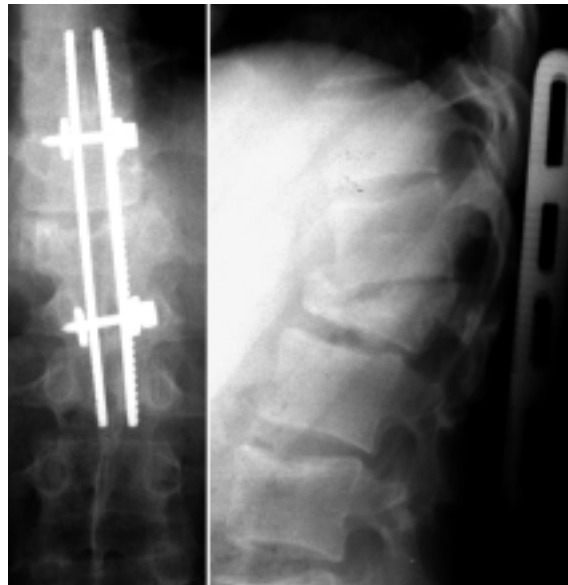


anterior fusion occurred but did not mention an appropriate time period. Holdsworth (1963), advised two to three weeks of bed rest for “wedge compression fractures” but seemingly found the burst fractures less “stable” than Nicoll and found it necessary to immobilize the spine by a plaster. He also failed to give a time period. In his review article of 1970, however, he advised for wedge fractures two to three weeks of bed rest followed by a light polythene jacket for eight to twelve weeks; for the “burst” fractures immobilization of eight to twelve weeks in a plaster bed followed by a few weeks’ support in a light jacket (Holdsworth 1970). At the University Hospital of Utrecht, patients with neurologic involvement were kept in bed for 4-6 months in the 1960’s (Tulleken 1971). It was common practice in the clinics of van Linge at the University Hospital Rotterdam in the 1980’s to keep patients with a “burst” fracture in bed with a plaster corset for six to twelve weeks (Klerk 1993).

The possible deleterious effects of long immobilization and bed rest, however, did not go unnoticed. Weitzman (1971) noted that a poor outcome in some patients “appears to be proportional to the length and duration of treatment”. In the United States, the ever-more-expensive hospital beds prompted the proponents of conservative treatment to evaluate these schemes critically. Mumford et al (1993/a), reporting very good results of conservative treatment of burst fractures, were nevertheless unhappy about the long hospital stay and adjusted the duration of bed rest and bracing to the “extent and severity of the injury”. The mean duration of hospitalization of their 47 patients was  $28.5 \pm 13.6$  (2-61) days, bed rest  $31.3 \pm 14.2$  (7-68) days, and bracing  $11.9 \pm 6.1$  (2-24) weeks. They finally recommended four weeks of bed rest followed by 12 weeks of bracing for burst fractures without neurologic deficit. Cantor et al (1993), also from the US, went a step further and treated their 33 patients with thoracolumbar junction burst fractures without neurologic involvement or radiological signs of posterior disruption, with a total contact extension orthosis as soon as their medical condition permitted. The average hospital stay was 10 days. The average duration of immobilization was not mentioned. Although they failed to obtain follow-up on 15 out of 33 patients, they concluded that this regime was safe and effective for this sub-group of patients.



**Figure 1.13:**  
*Spinal process fixation  
 plates. This  
 radiogram belongs to  
 a patient operated on  
 in the former Soviet  
 Republic of Georgia in  
 1991.*



“Conservative treatment”, in short, remains an ill-defined group of treatment regimes varying from direct mobilization with a plastic jacket to extensive periods of plaster immobilization and bed rest. The differing inclusion and exclusion criteria in these regimes by different authors also reflect the confusion and uncertainty about primary and secondary stability of these injuries.

#### 1.2.4.2 ADVANCES IN OPERATIVE TREATMENT TECHNIQUES

Development of safe anesthesia and aseptic techniques made surgical intervention in the spine beyond a minimal laminectomy feasible from the beginning of the century. Hibbs (1922), who is credited for the first spinal fusion operation in 1911, reported good results with spinal fusion for persistent pain and disability after spinal fractures. This was followed by reports by Howorth in 1939 of good results of spinal fusion for recent as well as late fractures (Howorth 1964). The first “instrumentation” of spine, however, was already reported in 1891 by Hadra in the Transactions of the Texas Medical Association (Howorth 1964). He reported the use of metal wires





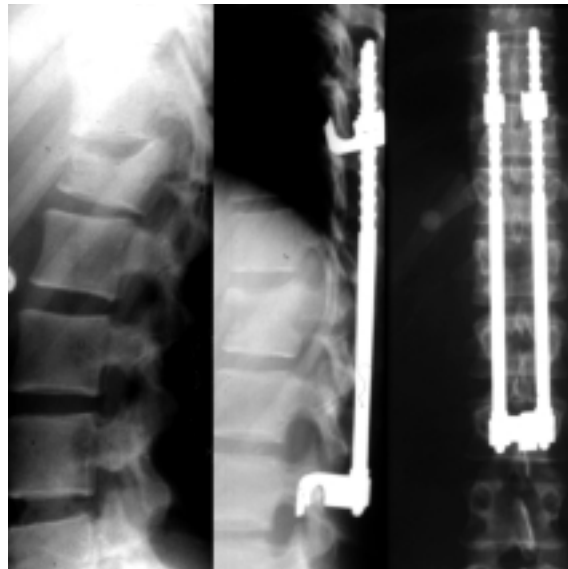
**Figure 1.14:**  
*The plates in fig 1.13 removed.*

between the sixth and seventh cervical spinous processes in a patient with a sixth cervical fracture. His patient unfortunately got infection and the wire had to be removed. Cone and Turner (1937) successfully developed this internal fixation technique of the cervical spine. Fixation of the thoracolumbar spine, however, proved to be much more difficult. In the 1940's internal fixation of the spine by double spinous process plating was tried (Straub 1949, Williams 1963). These plates were fixed to the spinous process with a 3-mm diameter bolt. Their use resulted in a high percentage of failure, with the implant cutting out the spinous process (Roberts 1969). Lewis and McKibbin (1974) reported implant failure in 9 of their 27 patients. These plates however have apparently survived into the 1990's in the former USSR. We have treated a patient from the former Soviet republic of Georgia, who was operated on with such a plate as late as 1991 (Figs. 1.13, 1.14).

Harrington instrumentation, which was developed for scoliosis surgery in the late 1950's (Harrington 1962), was soon applied to traumatic conditions (Fig. 1.15). Dickson (1973) reported use of dou-



**Figure 1.15:**  
*Fracture reduction  
and fixation with  
Harrington rods.*

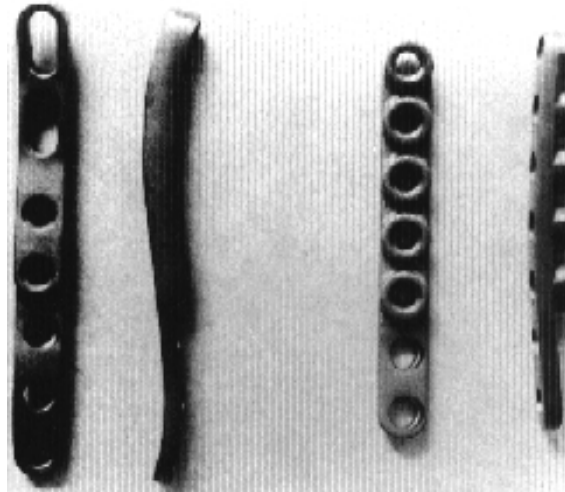


**Figure 1.16:**  
*Halotibial traction on  
a Stryker frame for  
reduction before  
Harrington fixation  
(Veldhuis 1993).*



ble Harrington distraction rods for stabilization of thoracolumbar fractures. For the first time, effective reduction and stabilization of these fractures became possible (Jacobs 1980). Reduction was achieved through gradual distraction. Halotibial traction was also described for preoperative reduction (Veldhuis 1993) (Fig. 1.16). In





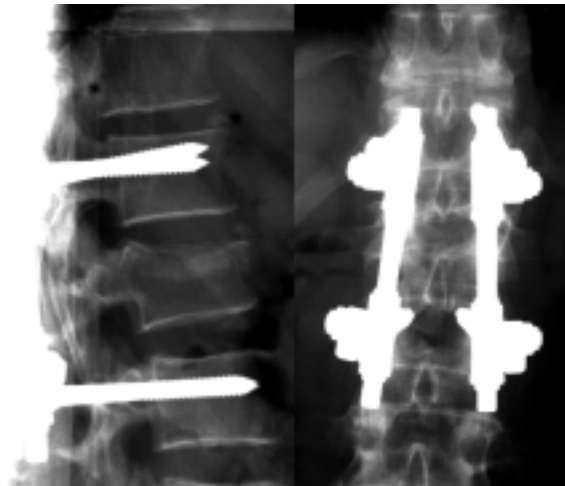
**Figure 1.17:**  
*Roy-Camille plates  
that were used in  
combination with  
pedicle screws.*

the 1970's and 1980's, the Harrington distraction system became standard operative procedure worldwide. However, hook dislodgment and loss of fixation was common (Yosipovitch 1977). Another problem was the necessity of immobilizing a large portion of the spine to achieve stable fixation (Akbarnia 1994). The usual procedure was “instrument long, fuse short” i.e. fixation of three segments proximal and three segments distal and a posterior fusion between the segments directly adjacent to the fractured vertebra. This was later modified to three segments above and two segments below by using interspinous or translaminar wire fixation, or sublaminar wire fixation after Luque, which would provide a segmental fixation (Wenger 1984, Floman 1986). Another problem was the “flat back” syndrome created by the straight Harrington rods (Moe 1977). Evolution of the Harrington system to the Cotrel-Dubousset technique (Cotrel 1988) solved some of these problems. Contouring of the rods and segmental fixation became possible (Farcy 1987), however the problem of long segment instrumentation remained.

One of the most important developments was the invention of transpedicular fixation techniques. Vertebral screw fixation was first reported by King (1944). He described placement of screws through the facet joints. Boucher (1959) improved the purchase of the screws



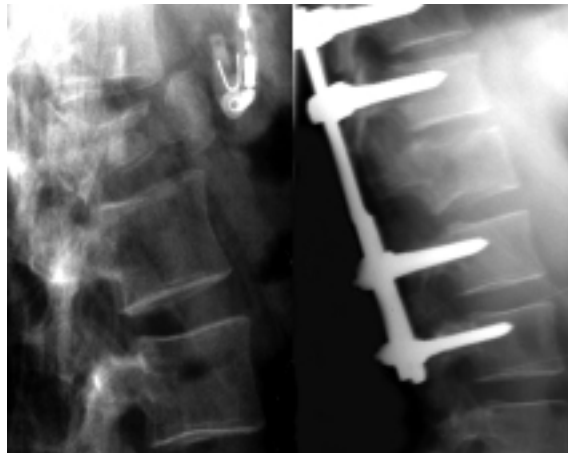
**Figure 1.18:**  
*Fixateur interne*  
of Dick.



by putting them in the pedicles of the caudal vertebra. Roy-Camille et al (1970) reported the first use of posterior plates with screws positioned sagittally through the pedicles. They had been using this system since 1963 for various spinal disorders, including fractures, with encouraging results (Fig. 1.17). This superior fixation technique was quickly adapted to the treatment of fractures (Dick 1985, Edwards 1986). The major benefit of this technique was its ability to obtain reduction of fractures and to maintain physiologic contour of the spine while instrumenting the fewest levels in comparison to the Harrington system. In the 1980's and 1990's posterior transpedicular fixation devices became standard operative treatment of thoracolumbar spine fractures (Figs. 1.18, 1.19).

Apprehension over the bony fragments compressing the canal, now superbly imaged with CT, led some surgeons in the 1970's to develop anterior decompression techniques. Bohlman (1981) popularized the procedure for anterior neural compression by direct anterior decompression and strut grafting. Anterior approaches to the thoracolumbar spine had actually been developed for anterior release and correction of scoliotic deformities. But anterior decompression in an acute fracture necessitated the removal of the vertebral body and discs and utterly destabilized the vertebral column. Strut grafting alone did not provide sufficient stability. Instrumentation to stabilize





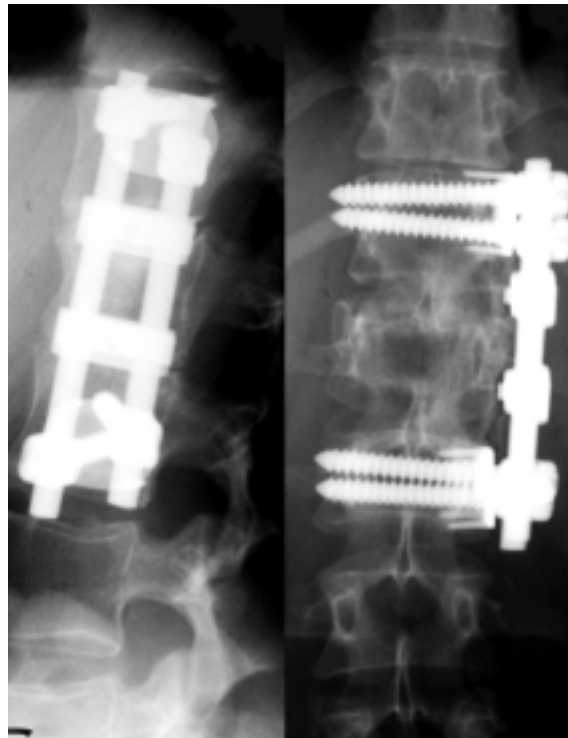
**Figure 1.19:**  
*Reduction and  
fixation with Isola  
instrument.*

such an unstable vertebral column was not easy to develop. Dunn (1984) was the first to develop an anterior distraction fixation device for the management of lumbar burst fractures. However, a number of fatal aortic and common iliac aneurysms as a result of the bulkiness of the device and its proximity to great vessels soon led to the removal of the implant from the market. Kaneda et al (1984) developed a similar device with a lower profile, which proved to be a safe and effective implant for use in the thoracolumbar junction and the lumbar spine (Fig. 1.20). Kostuik (1983, 1988), who became a fervent proponent of anterior decompression, adapted the Harrington system for anterior use. Application of some other successful posterior devices as anterior constructs, however, led to higher complication rates (Been 1991).

A meta-analysis of surgical treatment alternatives for fixation of unstable fractures of the thoracic and lumbar spine by Dickman et al (1994) showed a superior performance of pedicle screw constructs in comparison with hook-rod systems, Luque rectangles and anterior systems. They concluded that pedicle screw devices performed satisfactorily with respect to pain, function, and complications. According to a preliminary report of the prospective multi-center survey of operative treatment of thoracolumbar spine fractures in Germany, posterior fixation alone results in the lowest rate of complications and revisions. In this report, complication and revision rates were for



**Figure 1.20:**  
*Anterior fusion with  
Kaneda device.*



posterior alone 4.2%, for anterior alone 10.8%, and for combined anterior-posterior 7.6% (Knop 1998).

#### **1.2.4.3 ADVANCES IN THE TREATMENT OF NEUROLOGIC INJURY**

The First World War, with its massive number of injuries allowed observations of different neurological injury patterns on a large scale. Head and Riddoch (1917), Holmes (1915) and Böhler (1929) gave accounts of spinal cord injury at various levels. Precise descriptions of clinical symptoms according to various levels of injury were completed. But the prospects of survival of such a patient was no better than at the time of the Edward Smith papyrus. It was still “an ailment not to be treated” and Avicenna was still right in his conviction that a spine fracture with cord injury was fatal. Walker (1937)







estimated that the total mortality rate due to urinary sepsis alone in British soldiers with spinal injuries in the First World War was 80%. Decompressive laminectomy remained controversial although it gained powerful supporters in the US. Frazier and Allen in their highly influential 1918 textbook, stated that “the fact remains that there are records of function recovered that without operation would not have been anticipated” (Frazier 1918). They drew attention to a better general care of the patient to avoid bedsores and urinary infection. Their disciple Munro (1943), who founded a spinal center in 1936 at the Boston City Hospital, became a key figure in the management of the paraplegic. He believed that the treatment of the patient’s spine was only of secondary importance and that no effort should be made to reduce a fracture. He maintained that, with good care, traumatic paraplegia should not be fatal and if the patient had a good pair of arms he or she could be returned to a useful independent existence. He insisted on a meticulous preventive program against pressure sores and urinary tract infection. His views were widely adopted for the treatment of American soldiers during the Second World War and led to dramatic decreases in the mortality rates of traumatic paraplegia.

Ludwig Guttman, a well-known neurologist and neurosurgeon in Germany who fled to England just before the second world war, founded the first spinal injury unit in Europe following the methods of Munro (Guttman 1973). He introduced intermittent catheterization and a rigorous system of turning patients from prone to supine and back every two hours night and day to prevent pressure sores. He is credited with the foundation of British spinal injury units with a high standard of treatment. He considered an operation on the spinal cord “irresponsible meddling”. His authority led, as a result, to a virtual extinction of decompressive laminectomy in this period in the United Kingdom.

Whether decompression is helpful for neurologic recovery is still debated. Especially after the introduction of stabilization techniques that eliminate the destabilizing effects of laminectomy alone, surgical decompression again became a hot topic. Proponents of a more conservative approach defended the position that surgical decompression does not improve the chances of neurologic recovery in comparison to



conservative treatment (Frankel 1969, Tulleken 1971, Guttman 1973, Braakman 1986, Braakman 1991). These authors reported improvement by at least one Frankel grade in 65-70% of patients treated conservatively. Tulleken (1971), in his study of 146 patients with traumatic thoracolumbar fractures with neurologic involvement could not find a difference in neurologic recovery between conservative treatment or decompressive laminectomy, although he found a clear difference in the prognosis between myelum and cauda injuries. He concluded, however, that “decompressive laminectomy is indicated in cases in which the radicular lesion dominates the syndrome”. Gertzbein et al (1988), on the other hand, reported 83-88% improvement with surgical decompression, although they could not find a relation with the amount of canal encroachment or surgical decompression and the rate of recovery. They could not find a difference between anterior or posterolateral decompression techniques. Hu et al (1993) also showed higher improvement rates after surgical decompression but failed to find a difference between anterior and posterolateral decompression. In the multicenter spine fracture study this issue, too, was studied (Gertzbein 1992). They concluded that because of the differences in fracture type as well as neurologic scores in the nonsurgical patients compared to the surgical patients, it was difficult to compare the effectiveness of treatment. The initial deficits in the nonoperated patients were not as profound as those treated operatively. Nevertheless they still found it possible to make a number of important observations:

- The surgical and nonsurgical patients improved *at the same rate* through 2 years.
- The Motor Scores showed the same findings
- At 1 year, the surgical patients showed a significantly *greater relative improvement* in the Motor Score. This difference was maintained at the 2-year evaluation point
- Comparing the neurologic status of patients with *partial* neurologic deficit undergoing posterior versus anterior (or combined) surgery ... the findings suggest that anterior surgery improves the neurologic outcome in a subset of patients.

They concluded that “ because of the differences in the neurologic picture before surgery, it is not possible to make a dogmatic statement





regarding the efficacy of surgery; the nonoperated patients had a much better starting point. This issue is still unresolved.”

The difficulty of comparison of patients with neurologic involvement was already pointed out by Tulleken in 1971: “The fact that cord lesions as well as radicular lesions are incomplete in many cases, gives rise to erratic neurological syndromes which have little in common”.

### 1.3 ARTISTIC EXPRESSIONS OF SPINAL INJURY

No history of spinal injury is complete without an account by a victim of such a disaster. And who can better express the feelings of a victim better than an artist who experienced such an injury? The famous Mexican artist Frida Kahlo (Magdalena Carmen Frida Kahlo y Calderón, 1907-1954) was such an artist. At the age of 18 she was wounded in a bus crash in Mexico City (Herrera 1983). Her spinal column was broken in three places in the lumbar region. In the letters she wrote from the hospital there was one somber refrain: No hay remedio - there is no remedy. “One must put up with it” she wrote “I am beginning to grow accustomed to suffering”. During the rest of her life pain became a central theme for Frida and her art. Although she became a celebrated artist in her own right, as well as famous due to her marriage to the communist muralist Diego Rivera and her romantic affair with Lev Davidovitch Trotsky, the accident which led to her “broken column” haunted her throughout her life. She had a constant pain in her spine and right leg. She had at least thirty-two surgical operations, most of them on her spine and right leg. She painted the “Broken Column” (front cover) in 1944, after she had again undergone spine surgery and was confined in an apparatus. A disjointed entry in her diary at that time reads: “To hope with anguish retained, the broken column, and the immense look, without walking, in the vast path . . . moving my life created of steel.”

The problems with her spine broke her slowly. At her last exposition in 1953 she said: “I am not sick. I am broken. But I am happy as long as I can paint”. In her diary the last item was referring to another of her masterpieces concerning her ‘broken column’ (back cover):

Arbol de la Esperanza  
mantente firme.  
(Tree of Hope keep firm.)





**CLASSIFICATION OF THORACOLUMBAR  
SPINE FRACTURES**



**CHAPTER 2**

## 2.1 FRACTURE CLASSIFICATION SYSTEMS: DO THEY WORK AND ARE THEY USEFUL?

Fracture classification schemes are considered necessary tools as a conceptual framework for diagnosis and treatment. Furthermore they are thought to be systems for communication about the relative severity of the injuries and the result of different treatment options. However, the usefulness of these schemes has been a matter of intense debate after an editorial in the American Journal of Bone and Joint Surgery (Burstein 1993). The author of this editorial, Albert Burstein asked in conjunction with two articles in the same issue: Fracture classification systems: Do they work and are they useful? He argued that:

“Fracture classification systems are, in effect, tools. The purpose of the tool is to help the surgeon to choose an appropriate method of treatment for each and every fracture occurring in a particular anatomical region. The classification tool should not only suggest a method of treatment; it should also provide the surgeon with a reasonably precise estimation of the outcome of that treatment. .. Generally we think of an orthopedic tool as working if it produces the same desired results, time after time, in the hands of anyone who is likely to use it. Thus, each practitioner should produce the same classification every time the same patient data are reviewed (intraobserver reliability or repeatability), and different practitioners should agree on the classification of the data for a particular patient (interobserver reliability)... to use this tool before its workability has been proved is inappropriate.... Any classification scheme, be it nominal, ordinal, or scalar, should be proved to be a workable tool before it is used in a discriminatory or predictive manner...Once the tool has been shown to be functional, the next step in the process is to prove that it is useful. This step requires clinical studies in which the classification has been used as the basis for the choice of treatment”.

All this discussion had actually started as a result of an evaluation of the Neer classification system for proximal humerus fractures, which proved to be a very unreliable scheme despite its widespread acceptance and use since 1970! If the orthopedic community has failed in the proper evaluation of something relatively simple as fractures of proximal humerus, what to think of the complex injuries of a com-





pound structure such as the spine? Unfortunately there have been no attempts of verification of different classification systems of the spine injuries. No studies are known about the interobserver reliability and intraobserver reproducibility of any of these schemes. There is scarce data about the predictive value of some of these classification systems, which proved to be bad.

At this point one should remember Pascal: “there is great freedom of definition and definitions are never subject to contradiction, for nothing is more permissible than to give whatever name we please to a thing we have clearly pointed out “. Without verification by the practice of complex reality no definition or classification can be free from the fallacy as beautifully depicted by the great Argentinean writer Borges in one of his stories:

Categorization scheme of animals in an ancient Chinese encyclopedia entitled Celestial Emporium of Benevolent Knowledge:

On these remote pages it is written that animals are divided into:

- a. those that belong to the Emperor,
- b. embalmed ones,
- c. those that are trained,
- d. suckling pigs,
- e. mermaids,
- f. fabulous ones,
- g. stray dogs,
- h. those that are included in this classification,
- i. those that tremble as if they were mad,
- j. innumerable ones,
- k. those drawn with a very fine camel's hair brush,
- l. others,
- m. those that have just broken a flower vase,
- n. those that resemble flies from a distance.



## 2.2 CLASSIFICATION OF THORACOLUMBAR SPINE FRACTURES

### 2.2.1 EARLY CLASSIFICATION SCHEMES

There has been a great deal of controversy about the classification of fractures of the thoracolumbar spine. Böhler made the first attempts at classification in 1929. Since then the difficulty of a comprehensive classification has been recognized by all authors attempting to conceptualize a system. The main difficulty lies in the fact that, a) unlike the fractures of long bones, the pattern of spine fractures may be progressive, evolving into an increasing deformity, and that b) the spine fractures represent complex injuries of a structure composed of parts with different susceptibility to injury and different healing potentials. The classification of Böhler included five types (Böhler 1943):

1. Compression fracture with corpus injury.
2. Flexion-distraction injuries with anterior injury due to compression fracture and posterior injury due to distraction.
3. Extension fractures with injury to the anterior and posterior longitudinal ligaments and posterior arch injuries.
4. Shear fractures.
5. Torsion injuries.

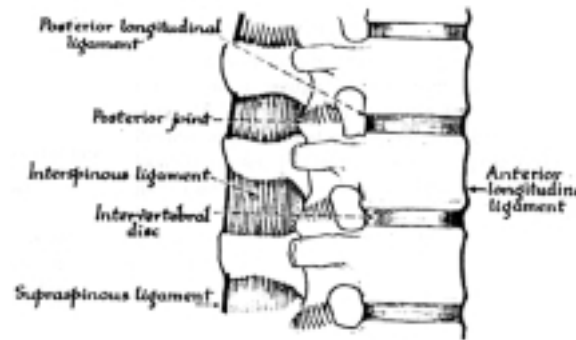
The efforts of Watson-Jones (1943) and Nicoll (1949) were more directed to define instability patterns so that the classification can be used as a predictive tool and a guide for treatment. Watson-Jones was the first who introduced the concept of “instability”. He recognized the importance of ligamentary injuries for the stability of the spinal column. Nicoll, based on a study of 166 fractures and fracture-dislocations in 152 miners during the period 1939-1945, classified the fractures on an anatomical basis into four main types:

1. Anterior wedge fracture.
2. Lateral wedge fracture.
3. Fracture-dislocation.
4. Isolated fracture of the neural arch.

He was the first to recognize the role of different structures in the generation of different patterns of fractures. He pointed out to four different structures involved: the vertebral body, the disc, the intervertebral joints and the interspinous ligament. He called the disc the







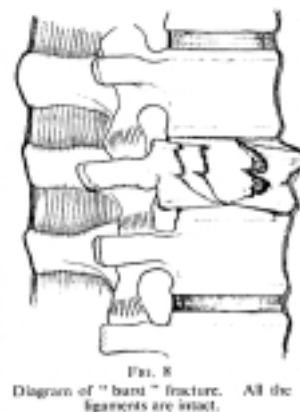
**Figure 2.1:**  
The two columns  
according to  
Holdsworth (1963).

fulcrum of the motion segment: “ If the fulcrum remains intact, any degree of hyperflexion capable of producing even minimal wedging of the vertebral body exerts great leverage on the interspinous ligament. ... This is the sequence of events if the fulcrum remains intact; but in many cases the interspinous ligament is the stronger of the two and the disc itself is crushed”. He pointed also to the importance of differentiating between stable and unstable varieties and the danger of increasing neurology or increasing deformity of unstable injuries. Holdsworth (1963) tried to capture the problem of stability in a columnar spine concept. He tried to abstract the vertebral stability with an architectonic two-column concept (Fig. 2.1). This abstraction has been influential in the traumatology of the spine ever since. His anterior column consisted of the vertebral bodies and the intervertebral disc, a synarthrosis relying for their stability upon the immensely strong annulus fibrosus, as he called it. He called the posterior column the “posterior ligament complex” consisting of the diarthrodial apophyseal joints stabilized by the capsule, by the interspinous and supraspinous ligaments and the ligamenta flava. In his theory the integrity of this posterior column is crucial for the stability of the spine. He called all the injury patterns with an intact posterior column stable. With this classification he was actually defining the gross mechanical stability of the spine. He classified injuries into six groups:

1. Anterior wedge compression
2. Dislocation
3. Fracture/dislocation by rotation



**Figure 2.2:**  
*The “burst fracture”,  
 a stable injury  
 because all ligaments  
 are intact  
 (Holdsworth 1963).*



4. Extension injury
5. Burst fractures
6. Shear fractures.

He was the first to introduce the concept of the “burst fracture” which he described as a result of compression force rupturing one of the end plates and forcing the disc into the body of the vertebra causing it to burst out (Fig. 2.2). This mechanism of injury had actually been described earlier by Nicoll but he had failed to classify this injury as a separate entity. Holdsworth, following his two-column concept, called the anterior wedge compression and burst fractures stable and the other four unstable. He also pointed to the changing patterns of injury and the increasing incidence of these injuries: “Twenty years ago fractures of the spine were almost entirely the result of accidents occurring in the heavy industry, particularly coal mining, and therefore geographically restricted. Now the incidence is almost equal throughout the country, for whereas spinal injuries in heavy industry are decreasing, those from road accidents are greatly increasing” (Holdsworth 1963).

Although the concept of Holdsworth remained influential throughout the 1960’s and 1970’s it was criticized seriously from the beginning. Kelly and Whitesides (1968) demonstrated that bony fragments retropulsed from the body in burst fractures, which gave them a high potential for instability. Roberts and Curtiss (1970) were the first to





point to the late progression of deformities in the burst fractures with possible neurologic consequences. Roy-Camille et al (1970) emphasized in that context the role of the what they called the 'segment moyen' formed by the posterior part of the disc, annulus fibrosus, and the posterior longitudinal ligament, together with the pedicles and the facet joints. Louis (1977) tried to elaborate the spinal columns concept with the introduction of a three-column architecture of the spine. One column is the anterior, composed of the vertebral bodies and the discs; the other two columns are posterior, consisting of the facet joints, articular processes, and the isthmus. These three columns are connected by three arches: the neural arch connecting the two posterior columns and the two pedicles connecting the posterior columns with the anterior column. He tried to quantify instability with this structure. Each column counts as 1.0, the arches as 1/2, and the other elements as 1/4. Instability is defined by a total score of 2 or more. Meanwhile, Argenson and Dintimille (1976) had carried out a unique experiment on monkeys in which they severed the posterior ligaments and posterior part of the annulus fibrosus without causing any osseous injury. The monkeys, the only animals standing and walking erect and thus closest to the human condition, developed progressive kyphosis.

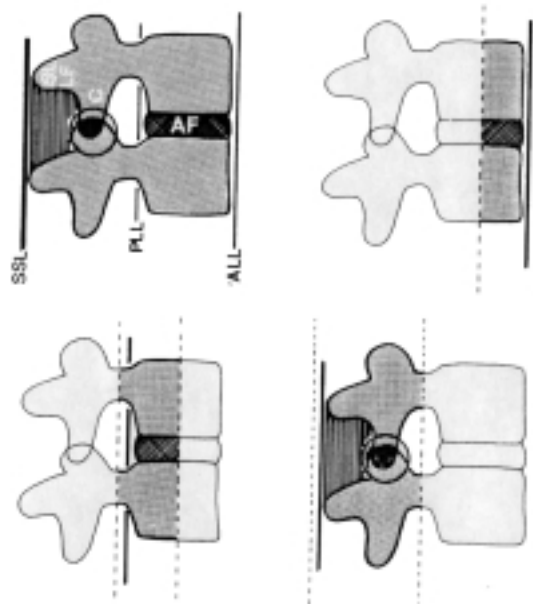
In the 1970's there was a growing awareness of the complexity of thoracolumbar injuries and their potential for progressive neurologic damage. Whitesides (1977) concluded that unstable burst-type fractures were the most common cause of neural injury. He also suggested that this might reflect a change in the patterns of trauma compared with the largely industrial accidents in Holdsworth's time.

### 2.2.2 THE THREE-COLUMN OF CT ERA

Large-scale use of computed tomography (CT) since the second half of the 1970's for spinal fractures provided a new insight into the fine structure of these injuries. The possibility of imaging the spine in transverse sections drew the attention to the comminution of the fractures and canal encroachment, which would not even have been suspected with traditional imaging techniques. These CT findings had a large impact on the thinking about a new classification system, based on the more accurate description of the extent and place of injury.



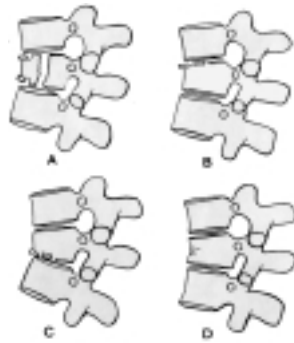
**Figure 2.3:**  
The three columns of  
Denis (1983/a).



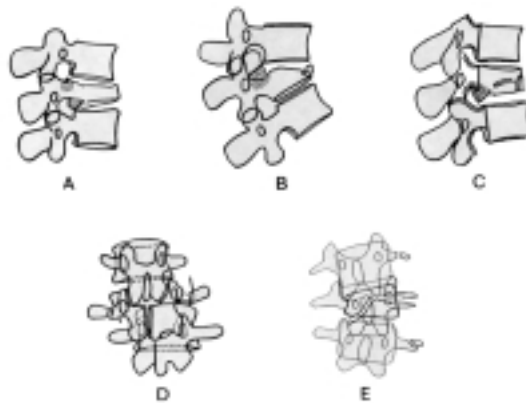
McAfee et al (1983), in their extensive studies showed the indispensability of computer tomography for an exact description of the injuries. Efforts in this direction in the early 1980's culminated in the three-column concept of Denis (1983/a), which has become the dominant classification system. His anterior column was formed by the anterior longitudinal ligament, the anterior annulus fibrosus, and the anterior part of the vertebral body; the middle column by the posterior longitudinal ligament, the posterior annulus fibrosus, and the posterior wall of the vertebral body and finally the posterior column by the posterior bony complex together with the posterior ligamentous complex (Fig. 2.3). According to this concept he classified fractures into four types:

1. Compression fracture
2. Burst fracture
3. Seat belt injuries
4. Fracture/dislocation.





**Figure 2.4:**  
*Compression fractures*  
*according to Denis*  
*(1983/a).*



**Figure 2.5:**  
*Burst fractures*  
*according to Denis*  
*(1983/a).*

**1- Compression fractures:** Failure under compression of the anterior column (Fig. 2.4). The middle column is intact. Subtypes:

- A. Fracture in the frontal plane
- B. Fracture of the anterior upper end plate
- C. Fracture of the anterior inferior end plate
- D. Failure of both endplates.

**2- Burst fractures:** Result from failure of the vertebral body under axial load (Fig. 2.5). Failure of anterior and middle columns under axial loads. Subtypes:

- A. Fracture of both end plates
- B. Fracture of the superior end plate
- C. Fracture of the inferior end plate
- D. Burst rotation.



**3- Seat-belt injuries:** Failure of both the posterior and middle columns under tension forces generated by flexion and distraction.

Subtypes:

- A. One level bone injury
- B. One level ligamentous injury
- C. Two level through bony middle column
- D. Two level through ligamentous middle column.

**4- Fracture dislocations:** Failure of all columns under compression, tension, rotation or shear. Subtypes:

- A. Flexion rotation
- B. Shear
- C. Flexion distraction.

Denis also introduced the concept of different degrees of instability:

- 1. **Instability of the first degree** is a mechanical instability with risk of progressive kyphosis. It applies to the severe compression fracture with posterior column disruption as well as to some of the seat-belt injuries.
- 2. **Instability of the second degree** is a neurologic instability. The so-called burst fracture falls into this category as further vertical collapse of the fractured vertebra may lead to more retropulsion of bone into the canal in the early post-traumatic phase and to higher risks of post-traumatic spinal stenosis after healing of the fracture.
- 3. **Instability of the third degree** is both a mechanical and a neurologic instability. Fracture/dislocations and unstable burst fractures are in this category.

Although this classification was a refinement in the understanding of the nature of these injuries, it was amenable to many simplifications and led to some confusion that still exist. Although Denis emphasized that his columns are formed by osseous and non-osseous structures, no attempt has been made to further the diagnosis of non-osseous injuries. The three-column concept was reduced to what is imaginable with CT. It has been simplified and reduced to a simple rule of the thumb, which states that any injury to two of the three columns, as seen on CT, i.e. bony injury, make the spine unstable. Further, an intact middle column has been seen as a guarantee of stability, although Denis mentioned some of these lesions as first-degree un-





stable. Also the differentiation between the first, second and third degree instability has been lost, leading to a vague, poorly defined and alarming instability concept, which has remained dominant during the past decade.

Despite its widespread acceptance there has been criticism of the Denis classification and attempts to modify it. Ferguson and Allen (1984) called the columns a poor semantic choice because these tissues do not anatomically or biomechanically resemble a column. They claimed that “the term, although appealing for its verbal ring, is anatomically and biomechanically incorrect “. They suggested a mechanistic classification instead, according to a presumed mechanism of injury deduced from the patterns of tissue failure. McAfee et al (1983) suggested a division of the burst fractures as stable and unstable. Finally Farcy et al. (1990) modified the Denis classification to include both bone and soft tissue injuries in each of the three columns of a motion segment. They developed a scheme of instability graded from 1 to 6, with injuries greater than or equal to grade 3 being unstable. But they also failed to develop diagnostic means to make the distinction between bone and soft tissue injuries.

### 2.2.3 THE CONCEPT OF STABILITY

This continuing effort to classify spinal fractures reflects the difficulties encountered in prediction of the stability of these injuries. Stability has been a major issue in spine surgery in general, but it has been poorly defined and has led to different interpretations. Biomechanicians and clinicians tried to develop a reproducible stability concept. Nicoll (1949) defined the stability of the spine as a condition in which there is no increased deformity or neurologic deficit over time. Whitesides (1977) called a spine unstable if deformity progressively leads to increasing neurologic compromise. Denis’ “degrees of instability” added to the confusion. White and Panjabi (1978) had actually devised the most comprehensive definition:

“Clinical instability is defined as a loss in the ability of the spine under physiologic loads to maintain relationships between vertebrae in such a way that there is neither damage nor subsequent irritation to the spinal cord or nerve roots. In addition there is no development of incapacitating deformity or pain due to structural changes.”



From this discussion we can conclude that a meaningful categorization of the stability of spine is supposed to address different *kinds* of stability in place of different *degrees*. A surgeon confronted with a patient with a spinal fracture stands for the task of evaluating three *kinds* of stability:

1. Immediate mechanical stability
2. Neurologic stability
3. Long-term stability

Any classification system or biomechanical concept should be able to provide the surgeon with reliable predictions about these different *kinds of stability*.

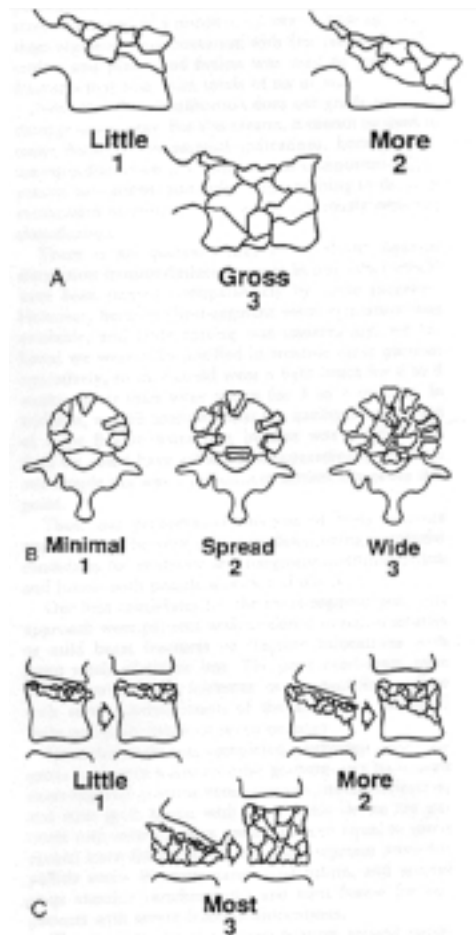
#### 2.2.4 THE LOAD-SHARING CLASSIFICATION

Two recent efforts to rationalize the classification schemes of thoracolumbar spine fractures should be mentioned. The first one is the load-sharing classification proposed by McCormak et al (1994). This proposal is a specific elaboration of the Denis system with a specific problem in mind. The authors were disturbed by the high rate of failure of posterior fixation in their patients with three column fractures and fracture dislocations, and searched for factors predictive of this failure. Their conclusion was that the degree of comminution of the vertebral body together with the apposition of fragments and the degree of deformity are factors predictive of the failure of posterior fixation. This is actually a reappraisal of the observations by Nicoll (1949) who called the comminution of the vertebral body one of the major factors concerned in redisplacement after the reduction of vertebral fractures. The authors developed a system of rating for (Fig. 2.6):

- A. comminution of the vertebral body:
  - little (1 point),
  - more (2 points),
  - gross (3 points)
- B. apposition of fragments:
  - minimal (1 point),
  - spread (2 points),
  - wide (3 points);







**Figure 2.6:**  
Load sharing  
classification  
according to  
McCormack (1994).

- C. deformity correction.  
little (1 point),  
more (2 points)  
most (3 points).

They observed that, in their series of 28 patients, all 10 cases with a screw fracture had a sum of 7 or more points, and no patient with a sum of 6 or less points had a screw fracture. This trait of thinking about classification of these injuries may prove to be productive as it



addresses a specific practical problem of a certain treatment modality and proposes the development of predictive factors without pretensions of an all-encompassing classification scheme. One of the criticisms is the lack of verification (inter- and intra-observer variability) of their measurements. Their transfer of highly subjective evaluations on plain radiograms and CT's to a quantitative system is prone to high inter-observer variations and should be validated. Another important point is the omission of soft tissue injury. Even Nicoll with his limited imaging facilities concluded that "comminution is almost invariably associated with damage to the disc, the interspinous ligament, or both, in which case some collapse is inevitable whatever happens to the vertebral body...When the disc is damaged, redisplacement is inevitable, for the disc has no blood supply and it is incapable of repair ". Extension of this load-sharing classification with a classification of changes in the disc space may improve its predictive value in different treatment modalities.

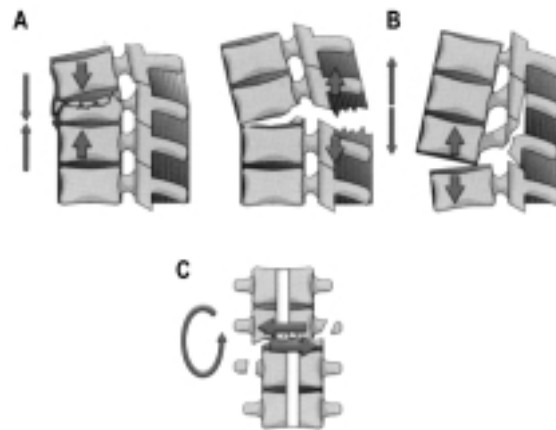
## 2.2.5 THE AO CLASSIFICATION

The classification scheme of the AO group is a culmination of efforts of many practitioners during a 10-year period (Magerl 1994). The five authors, Magerl, Aebi, Gertzbein, Harms and Nazarian, all with extensive experience in the treatment of these injuries and classification of fractures, claim their classification system to be "comprehensive". This scheme carries the authority of the AO foundation and many prominent spine surgeons, and will probably be dominant in the near future. But one should remember the warnings of Nicoll (1949): " Nevertheless an assumption it remains, and an assumption that has the most vital repercussions on treatment. The fact that it is held so widely and authoritatively is yet another reason for submitting it to careful and critical examination".

This scheme is primarily based upon the pathomorphological characteristics of the injuries. Three main categories with a common injury pattern, the types, are formed (Fig 2.7):

- **Type A:** Vertebral body compression.
- **Type B:** Anterior and posterior element injury with distraction.
- **Type C:** Anterior and posterior element injury with rotation.





**Figure 2.7:**  
Essential characteristics of the three injury types according to Magerl et al (1994).  
Type A: Compression injury of the anterior column; Type B: Two column injury with transverse disruption; Type C: Two column injury with superimposed rotation.

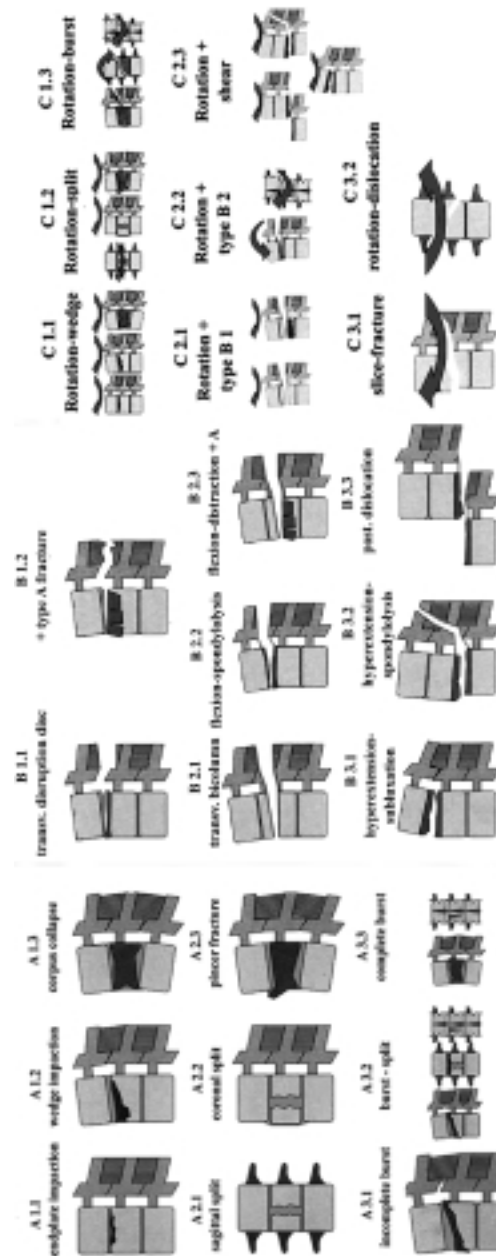
It is remarkable that the authors abandoned the three-column concept and went back to the two-column concept of Holdsworth, i.e. an anterior column consisting of the vertebral body and the disc and a posterior complex. They also went back to the mechanistic classification of Ferguson and Allen (1984) for identification of common denominators of the types: type A injuries represent compression forces, type B tensile forces and type C axial torque. A recent study showed good relation between this type categorization of the scheme and the resulting mechanical instability in a cadaveric fracture model (Lange 1998). For further subclassification, the authors used the common AO 3-3-3 grid. Subclassification of the type B and C injuries essentially follows the subclassification of type A injuries (Fig. 2.8).

**Type A injuries:** Focus on the fractures of the vertebral body. There is no or insignificant injury to the posterior column. These injuries are supposed to be caused mainly by axial compression. The subclasses of the type A:

- **A1:** **Impaction fractures.** The deformation of the vertebral body is due to compression (plastic deformation) of the cancellous bone rather than fragmentation.
  - A1.1:** endplate impaction with minor wedging up to 5°.
  - A1.2:** wedge impaction with loss of anterior vertebral height resulting in an angulation of more than 5°.



**Figure 2.8:**  
Group and subgroup  
divisions of Type A, B  
and C fractures.





- A1.3: vertebral body collapse. Symmetrical loss of vertebral body such as observed in osteoporotic spines without significant extrusion of fragments.
- A2: **Split fractures.** The vertebral body is split in the coronal or sagittal plane with dislocation of fragments and filling of the defect with disc material.
  - A2.1: Sagittal split fractures.
  - A2.2: Coronal split fractures.
  - A2.3: Pincer fracture, in which the central part of the body is crushed and filled with disc material.
- A3: **Burst fractures.** with fragments of posterior wall extruding in the canal. The posterior ligamentary complex is intact.
  - A3.1: Incomplete burst fractures. Burst of the upper or lower half of the body.
  - A3.2: Burst-split fracture. Burst of one-half of the vertebra and sagittal split of the rest.
  - A3.3: Complete burst fracture. Entire body is burst. Subclassified in three types:
    - A3.3.1: Pincer burst fracture.
    - A3.3.2: Complete flexion burst fracture.
    - A3.3.3: Complete axial burst fracture.

**Type B injuries:** The main criterion is a transverse disruption of one or both spinal columns. The subclasses of type B:

- B1: Posterior disruption predominantly ligamentous.
  - B1.1: Associated with transverse disruption of the disc.
    - B1.1.1: Flexion-subluxation.
    - B1.1.2: Anterior dislocation.
    - B1.1.3: Flexion-subluxation or anterior dislocation with fracture of the articular processes.
  - B1.2: Associated with type A fracture of the vertebral body.
    - B1.2.1: Flexion-subluxation associated with type A fracture.
    - B1.2.2: Anterior dislocation associated with a type A fracture.



- B1.2.3:** Flexion-subluxation or anterior dislocation with bilateral facet fracture associated with type A fracture.
- **B2:** Posterior disruption predominantly osseous.
  - B2.1:** Transverse bicolmn fracture.
  - B2.2:** Posterior disruption predominantly osseous with transverse disruption of the disc.
    - B2.2.1:** Disruption through the pedicle and disc.
    - B2.2.2:** Disruption through the pars interarticularis and disc (flexion- spondylolysis).
  - B2.3:** Posterior disruption predominantly osseous associated with type A fracture of the vertebral body.
    - B2.3.1:** Fracture through the pedicle associated with a type A fracture.
    - B2.3.2:** Fracture through the isthmus associated with a type A fracture.
- **B3:** Anterior disruption through the disc.
  - B3.1:** Hyperextension-subluxation.
  - B3.2:** Hyperextension-spondylolysis.
  - B3.3:** Posterior dislocation.

**Type C injuries:** Anterior and posterior element injuries with rotation. Two-column injury with rotational and/or translational displacement. Subtypes:

- **C1:** Type A with rotation
  - C1.1:** Rotation + wedge fracture.
  - C1.2:** Rotation + split fracture.
  - C1.3:** Rotation + burst fracture.
- **C2:** Type B with rotation
  - C2.1:** Rotation + type B1.
  - C2.2:** Rotation + type B2.
  - C2.3:** Rotation + type B3.
- **C3:** Rotational shear injuries.
  - C3.1:** Slice fracture.
  - C3.2:** Rotation-dislocation.





This classification represents a taxonomic beauty in that each and every injury can be fitted to a certain category. But one should not forget that the dream of a taxonomist might be the nightmare of a practitioner. The authors seem to realize this and declare that "... in clinical practice, application of the classification can be restricted to subgroups or even groups without the loss of information which is most important for defining the principal nature of the injury and the choice of treatment ". The all-encompassing nature of this scheme makes it prone to significant problems of inter- and intra-observer reliability. Independent observers not involved in the development of the scheme should test this. The authors claim that the severity of injury progresses from type A through type C as well as within the types. They define severity by several factors such as impairment of stability, risk of neurologic injury, and prognostic aspects, confirming the three kinds of stability mentioned before (Section 2.2.3). The authors' argumentation about the term 'instability' is quite clarifying. They seemed to have taken the necessary lessons from the confusions caused by the ill-defined 'instability' concept of Denis and others: " The term 'instability' on its own is of little use if it is not related to parameters defining the load beyond which a physical structure fails... Though any reduction of resistance against primary forces may be termed 'instability', a more precise identification of the type and degree of instability is necessary for the treatment modalities. There are injuries which are clearly stable and those which are clearly unstable when subject to forces of any direction and magnitude. Between these two extremes, there are many injuries of varying instability with flowing transitions regarding the quality and magnitude of instability. There are those with 'partial instability and simultaneously 'residual stability'... because the precise degree of instability cannot be defined for every injury, it would be hardly feasible to classify spinal injuries on a strictly progressive scale of instability ". This puts the surgeon back to the task of judging the three kinds of stability without the 'rule of the thumb' simplifications based on a reification of 'columns'. The authors discuss under each type of injury the forces against which a spine with such an injury would be 'unstable'. The stability of Type A injuries in compression may be intact or lost, depending on the extent of destruction of the vertebral body, but sta-



bility in flexion, although maybe reduced, is never completely lost since, by definition, the posterior ligamentary complex must be intact. The spine is also stable under longitudinal traction and in extension as the anterior longitudinal ligament is preserved. Type B injuries represent partial or complete loss of the tensile strength of the spine, often in addition to the loss of stability in axial compression. Sagittal translation can occur either anteriorly or posteriorly. Type C injuries are unstable in axial torque which in many cases is superimposed on the instabilities already present in types A or B. This discussion on the stability of injuries emphasizes the separation of discoligamentary injuries from osseous lesions. This differentiation is prominent in the whole scheme. But the authors fail to explain how this task should be done with the conventional radiograms and CT's. Their discussion of intactness or injury to various non-osseous structures is completely based on assumptions from a presumed mode of action of the injuring force without any means of confirmation by clinical or radiological examination. They admit that some Type B injuries in their series may have been incorrectly classified as Type A fractures. They correctly point to the different healing potentials of different structures of the spine and thus the importance of this differentiation. Advanced imaging techniques with MRI can clarify this important issue and may also increase the reproducibility of this comprehensive classification scheme. It can be expected that the main distinction level between the different types, based on judgements of a predominantly soft tissue injury would prove to be difficult because soft tissue injury patterns associated with spinal fractures are not yet sufficiently described. The authors did not mention MRI findings but theoretically, addition of MRI can potentially increase the reliability of this level of the classification. MRI has been shown to be capable of detection of ligamentary injuries and injuries to the disc and the endplate associated with thoracolumbar spine fractures in experimental and clinical studies (Kliewer 1993, Petersilge 1995, Terk 1997, Oner 1999/a). It has been suggested that future classifications should include MRI findings (Saifuddin 1996).





**THE AO CLASSIFICATION OF  
SPINAL FRACTURES: PROBLEMS OF  
REPRODUCIBILITY**



**CHAPTER 3**

### 3.1 INTRODUCTION

Fracture classification schemes are considered necessary tools as a conceptual framework for diagnosis and treatment. Furthermore they are systems for communication about the relative severity of the injuries and the result of different treatment options. However, classification schemes used for the peripheral skeleton have been shown to have poor to moderate inter-observer and intra-observer reproducibility (Andersen 1990, 1991, 1996, Brumback 1994, Dirschl 1997, Horn 1993, Johnstone 1993, Martin 1997, Nielsen 1990, Sidor 1993, Siebenrock 1993, Swiontkowski 1997, Thomsen 1991). This raises questions about the usefulness of any classification scheme about fractures, which represent a continuum of different injuries resulting from the chaotic processes of trauma.

Injuries of the thoracolumbar spine pose an even greater challenge for classification attempts due to the involvement of non-osseous structures aside from different fracture patterns (Section 2.2). Thoracolumbar spine fractures represent complex injuries of a structure composed of parts with different susceptibility to injury and different healing potentials. Böhler, who devised the first schematic classification of thoracolumbar fractures (Böhler 1930), already recognized this complexity. Subsequent concepts tried to capture the various injury patterns using architectonic abstractions such as columns. The two-column concept of Holdsworth was followed by the three column concepts of Louis and Denis (Holdsworth 1963, Louis 1977, Denis 1983/a). The main concern of these authors was the relation of different injury patterns to immediate and long-term mechanical and neurologic stability. There are, however, no studies known to us, which questioned the reproducibility of these concepts systematically.

The AO classification (Section 2.2.5) is the latest and the most sophisticated system for classification of these fractures. To our knowledge, no attempt has been made to study the reproducibility of this system. Our goals in this study were to determine the inter-observer reliability and intra-observer reproducibility of this classification scheme and to test the hypothesis that MRI would result in a better agreement about the type categorization of the fractures.





### 3.2 MATERIALS AND METHODS

Since 1994 we have obtained MRI's of all patients with a thoracolumbar spine fracture admitted to our hospital. T1 weighted (TR 578; TE 25) and T2 weighted (TR 2000; TE 100) images were obtained during the first week after admission. MR imaging was not possible in case of polytrauma necessitating long periods of assisted ventilation or emergency intervention before imaging could be obtained. Therefore the MR imaging for 13 patients was not performed. In 78 patients MRI's were obtained in the period September 1994-September 1997. 53 of these patients also had adequate CT's with multiplanar 2-D reconstructions. Standard AP and lateral radiograms, CT scans and MR images of these 53 patients were collected and filed in an anonymous fashion blinded for all patient data. Five observers participated in the study: one orthopedic spine surgeon, one general trauma surgeon, one neuroradiologist and two orthopedic residents in their fifth (resident 1) and third (resident 2) year of training respectively. In our hospital, a spinal injury work group consisting of the orthopedic spine surgeon, the general trauma surgeon, a neurosurgeon and the neuroradiologist meet weekly to discuss all patients with spinal injury. Orthopedic residents also attend these meetings. We have been using the AO classification in this work group since 1995, so each participant was acquainted with the scheme. Prior to the start of the study each participant read the original article by Magerl et al (1994) describing the basic concepts of the scheme. Each participant was provided with a visual representation of the classification with a short description of the classification at the first three levels of the scheme (i.e.. type, group, and subgroup such as A 1.1 or B 2.3). Observers were asked to note every fracture seen and to fill in a separate form for each of the fracture seen. Subsequently all five observers rated the files first only with radiograms and CT's and 6 to 8 weeks after the first rating with radiograms and MRI's. These ratings were used for inter-observer agreement between the five observers and intra-observer agreement between CT and MRI readings. 3 months after the first rating the orthopedic spine surgeon and the two orthopedic residents rated all the files again in the same manner. These ratings were used to determine the intra-observer agreement between the first and second CT and MRI readings.



Cohen's kappa test was used for inter- and intra-observer agreement. The guidelines proposed by Landis and Koch were used to categorize kappa values (Landis 1977): 0.00 to 0.20 slight reliability; 0.21 to 0.40 fair reliability; 0.41 to 0.60 moderate reliability; 0.61 to 0.80 substantial agreement; 0.81 to 1.00 almost perfect agreement. First the agreement on the presence and the levels of observed fractures were determined. For inter-observer measurements only the cases were included if in both of the readings a fracture was reported at the same level. According to the basic idea of the classification scheme the distinction between type A and the other two types is an essential feature concerning posterior column involvement. The crucial distinction at the type level is to determine whether the injury belongs to the common and more stable Type A or to the potentially more unstable Type B or C category. This distinction depends largely on the recognition of soft tissue involvement in transverse plane, which is expected to be more difficult with radiograms and CT's and, according to our hypothesis, would be better with MRI. For this reason we first measured the agreements for Type A and non-Type A (type B or C) distinction. Thus, the A / non-A distinction reflects essentially the judgment of the observer on the integrity of the posterior column. As the second level the agreements were measured on the separate Types (A, B, C). Because the basic subdivision of the types follows largely the subdivision of the Type A, agreement on groups and subgroups was measured for type A fractures only and this in case in both of the readings a type A fracture was reported. Finally agreement in all three levels was measured.

From the ten readings (one with CT and one with MRI for each participant) inter-observer agreement was measured separately for the CT and MRI readings. The agreement between the CT and MRI readings of each participant was also measured as intra-observer agreement between CT and MRI. Intra-observer agreement was measured between the two CT readings and the two MRI readings of the three participants who did the entire procedure for the second time. As a summary measure for the kappa coefficients, generalized kappas were used for the inter-observer agreement and mean kappas for intra-observer agreement.

Statistics were performed with SPSS/PC + version 5.0.1.





### 3.4 RESULTS

The classifications provided by the observers on the CT and MRI readings are shown in table 3.1. Multiple fractures in the same patient are reported under the same patient number with different levels. 76 fractures were reported at least once. 60 fractures were reported by all observers in every reading. The frequencies of different classes reported by the five observers on the CT and MRI readings are shown in table 3.2. The highest frequency of non-A reportage was by the orthopedic surgeon, the lowest by the resident 1. 20 of the total possible 27 categories were reported at least once.

Considering the inter-observer agreement of the number and level of the fractures the mean kappa value was 0.65 (0.53-0.94) for the CT readings and 0.62 (0.43-0.95) for the MRI readings. For this same issue the mean kappa between the CT and MRI readings of each participant was 0.77 (0.62-0.90).

The simple kappa values concerning the Type A / non-Type A distinction, Type categorization, Type A fractures group and subgroup, and agreement on all three levels (complete classification) are shown in tables 3.3, 3.4, 3.5, 3.6 and 3.7. Generalized kappas and mean kappas with the ranges are summarized in table 3.8. Considering the A / non-A distinction, the highest agreement on CT readings was achieved between the general surgeon and the resident 2, the lowest between the general surgeon and the resident 1; on MRI readings the highest agreement was achieved between the radiologist and the resident 1, the lowest by the resident 1 and the resident 2. For Type categorization, the highest values were achieved on CT between the general surgeon and the resident 2, lowest values by the general surgeon and the resident 1; on MRI readings the highest between the general surgeon and the radiologist. For type A group the highest values on CT were achieved between the orthopedic surgeon and the resident 2, lowest between the general surgeon and the radiologist; on MRI the highest between the radiologist and the resident 2, lowest between the resident 1 and the resident 2. For type A subgroup, on CT the highest values were achieved between the general surgeon and the resident 2, the lowest between the radiologist and the resident 1; on MRI the highest between the radiologist and the resident 2, the lowest between the resident 1 and the resident 2. Finally for the all three levels of the



PAT.	LEVEL	GEN. SURG		RADIOLOG.		ORT. SURG		RESID. 1		RESID. 2	
		CT	MRI	CT	MRI	CT	MRI	CT	MRI	CT	MRI
1	T7	B 2.3	A 3.1	A 2.3	A 2.3	B 2.3	B 2.3	A 3.3	A 3.3	B 2.3	B 2.3
2	L3	B 1.2	A 3.1	A 3.3	A 3.3	A 3.3	A 3.3	A 3.2	A 3.3	A 3.3	A 3.3
3	L1	A 3.1	A 1.2	A 2.3	A 2.3	A 3.3	A 3.3	A 3.1	A 1.2	A 3.3	A 3.3
4	L1	A 3.3	A 3.3	A 3.3	A 3.3	A 3.3	A 3.3	A 3.3	A 3.3	A 3.3	A 3.3
5	L1	B 2.3	A 3.1	B 2.3	A 3.3	B 1.2	A 3.2	A 3.1	A 3.1	B 1.2	A 3.3
6	L1	A 3.3	A 3.3	A 3.3	A 3.2	A 3.3	A 3.3	A 3.3	A 3.3	A 3.3	A 3.3
7	L3	B 2.3	A 3.1	A 3.3	A 3.3	A 3.2	A 3.3	A 3.1	A 3.1	B 2.3	A 3.1
8	L1	B 2.3	B 1.2	A 3.3	A 3.3	B 1.2	B 1.2	A 3.2	B 1.2	B 1.2	B 1.2
9	L1	A 1.2	A 1.2	A 1.3	A 1.3	B 1.2	B 1.2	A 1.2	A 1.2	A 1.2	B 1.2
10	T12	A 3.2	A 3.1	A 2.3	A 3.2	A 3.2	A 3.1	A 3.2	A 3.1	A 3.2	A 3.2
11	L1	A 2.1	A 3.3	A 3.1	A 3.1	A 3.1	A 3.1	A 3.1	A 3.1	A 3.3	A 3.3
12	L1	A 3.1	A 3.1	A 3.1	B 2.3	A 3.1	A 3.1	A 3.2	A 3.1	A 3.1	A 3.1
13	T12	A 1.2									
13	L1	A 3.1	A 1.2	A 1.3	A 1.3	A 3.1	A 3.1	A 3.1	A 3.1	A 1.3	A 1.3
14	T12	A 3.1			A 1.2		A 1.1				
14	L2	B 2.3	A 3.3	A 3.2	A 3.1	A 3.2	A 1.2	A 1.2	A 3.1	A 3.2	A 3.2
14	L3	B 2.3	A 1.2	A 3.3	A 3.3	A 3.3	A 3.2	A 3.2	A 3.3	B 2.3	B 2.3
15	T8	A 1.2	A 3.1	A 2.3	A 3.1	A 3.1	A 3.1	A 1.2	A 1.3	A 3.1	A 3.1
15	T11				A 1.1		A 1.1				
16	T12	A 3.2	A 3.2	A 2.2	A 3.3	A 3.2	A 3.2			A 3.2	
16	L3	B 2.3	A 3.3	A 3.3	A 2.3	A 3.3	A 3.3	A 3.3	A 3.1	A 3.3	B 2.2
17	L3	B 2.3	A 2.2	A 3.3	A 3.3	B 2.3	B 1.2	A 1.2	A 2.3	B 2.3	B 2.1
18	L1	A 1.2	A 1.2	B 1.2	B 3.2	B 1.2	B 1.2	A 1.2	A 2.3	B 1.2	B 1.2
19	T8	A 3.3	A 1.2	A 1.1	A 1.3	A 1.2	A 3.1				A 1.3
19	T11	A 1.2	A 1.2	A 1.1	A 1.2	A 1.2	A 1.1	A 1.2	A 1.2	A 1.2	A 1.2
19	L3	A 1.2	A 1.2	A 1.2	A 1.2	A 1.2	A 1.1	A 1.2	A 1.2	A 1.2	A 1.2
20	T12	A 3.1	A 1.2	A 1.2	A 1.2	A 1.2	A 3.2	A 1.2	A 1.2	A 1.2	A 1.2
21	T12	A 3.1	A 3.1	A 2.3	A 2.3	A 3.1	A 3.2	A 1.2	A 3.1	A 1.2	A 1.2
22	T12	A 1.1	A 1.1							A 1.1	
22	L1	A 3.2	B 1.2	B 1.2	A 1.3	A 3.2	A 3.1	A 2.3	A 3.3	A 3.2	A 3.2
23	L1		A 1.1	A 1.3	A 1.1	A 1.3	A 1.1	A 1.2	A 1.2		A 1.3
23	L2		A 1.2	A 1.3	A 1.1	A 1.3	A 1.1	A 1.2	A 1.2	A 1.3	A 1.3
23	L3		A 1.1	A 1.3	A 1.1	A 1.3	A 1.1	A 1.2	A 1.2	A 1.3	A 1.3
24	L1	B 2.3	A 3.2	A 3.2	A 3.2	A 3.3	A 3.3	A 3.3	A 3.3	B 2.3	B 2.3
25	L1	A 3.2	A 3.1	A 3.2	A 3.2	A 3.2	B 2.3	A 3.1	A 3.1	A 3.3	A 3.3
26	L2	A 3.1	B 1.2	A 1.3	A 1.3	A 1.2	A 1.2	A 1.2	A 1.3	A 1.2	A 1.2
27	T12	B 2.1	A 3.1	A 3.3	A 3.3	B 2.3	B 1.2	A 3.2	A 3.1	B 2.1	B 2.2
28	L1	A 3.2	A 2.3	A 3.3	A 3.3	A 3.3	C 1.3	A 3.2	A 3.3	A 3.3	A 3.3
29	T12	A 1.2	B 1.2	B 1.2	B 1.2	B 1.2	B 1.2	A 1.2	B 1.2	B 1.2	B 1.2



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PAT.	LEVEL	GEN. SURG		RADIOLOG.		ORT. SURG		RESID. 1		RESID. 2	
		CT	MRI	CT	MRI	CT	MRI	CT	MRI	CT	MRI
30	L1	A 3.1	B 1.2	A 2.3	B 1.2	A 3.1	B 1.2	A 1.2	A 1.2	C 2.2	C 2.2
31	T12	A 3.3	A 3.3	A 3.3	A 3.3	A 3.3	A 3.3	A 3.3	A 3.3	A 3.3	A 3.3
32	L2	A 3.3	A 3.3	A 3.3	A 3.3	A 3.3	B 2.3	A 3.3	A 3.3	A 3.3	A 3.3
33	L1	A 1.2	A 3.1	A 3.1	A 3.1	A 3.1	A 3.1	A 1.2	A 1.2	A 3.1	A 3.1
34	L1	A 1.2	A 1.1	A 1.2	A 1.2	A 1.1	A 1.1	A 2.1	A 1.2	A 1.2	A 1.2
34	L2	A 1.2	A 1.2	A 1.3	A 1.2	A 1.2	A 1.1	A 1.2	A 1.2	A 1.2	A 1.2
34	L4	A 1.2	A 1.1					A 1.2			
34	L5	A 3.2	A 3.3	A 3.3	A 3.3	A 3.3	A 3.1	A 3.2	A 3.3	A 3.3	A 3.3
35	L1	A 1.2	B 2.1	A 1.2	B 1.2	A 1.2	B 1.2	A 1.2	B 1.2	A 1.2	A 1.2
36	T3	A 3.2	A 3.3	A 3.3	A 3.3	B 2.3	B 2.3	A 3.3	A 3.3	A 2.3	A 3.3
36	T4			A 3.2	A 3.2	B 1.2	B 2.3	A 3.3	A 3.3		A 3.3
37	L1	A 3.3	B 1.2	A 3.3	A 3.3	A 3.2	A 3.1	A 3.1	A 3.1	A 3.3	A 3.3
38	L1	A 3.3	A 3.1	A 3.2	A 3.2	A 3.2	A 3.1	A 3.2	A 1.2	A 3.3	A 3.3
38	L5	A 3.3	A 3.3	A 3.3	A 3.3	A 3.3	A 3.3	A 1.2	A 3.3	A 3.2	A 3.2
39	L1	A 1.2	A 1.2	A 1.2	A 1.2	B 1.2	A 1.2	A 1.2	A 1.2	A 3.2	A 3.2
40	L1	A 3.3	A 3.3	A 3.3	A 3.3	C 1.3	A 3.3	A 3.3	A 3.1	A 3.3	A 1.2
41	T12	B 1.2	B 1.2	A 3.3	B 1.2	B 2.3	B 1.2	A 3.1	B 2.2	B 2.3	A 1.1
41	L1	A 1.1		A 1.1	A 1.1	A 1.2	A 1.1			A 1.1	A 1.1
42	L3	A 3.3	A 3.3	A 3.3	A 3.3	A 3.3	A 3.2	A 3.2	A 3.3	A 3.3	A 3.3
43	L1	C 1.3	C 1.3	C 3.2	C 3.2	C 1.3	C 2.1	C 1.3	B 1.2	C 1.3	C 1.3
44	T9	A 1.2	A 1.2	A 3.3	A 3.3	C 1.3	C 1.2	B 2.2	A 3.3	C 1.3	C 1.3
45	L1	A 3.1	A 3.1	A 2.3	A 3.3	A 3.1	A 3.1	A 3.1	A 3.1	A 3.3	A 3.3
46	L1	A 1.2	A 1.2	A 1.1	A 1.1	A 1.3	A 1.2	A 1.2	A 3.1	A 1.2	A 1.2
47	L1	A 1.2	A 1.2	A 1.2	A 1.2	A 1.2	A 1.1	A 3.2	A 1.1	A 1.1	A 1.1
47	L2	A 1.2	A 1.2	A 3.1	A 1.2	A 1.2	A 1.2	A 1.2	A 1.2	A 1.2	A 1.2
47	L3	A 3.3	A 3.1	A 3.3	A 3.3	A 3.2	A 3.1	A 1.2	A 3.1	A 3.3	A 3.3
48	T12	A 1.2	B 1.2	A 1.2	B 1.2	B 1.2	B 1.2	A 1.2	A 1.2	A 1.2	B 1.2
48	L2	A 1.2		A 1.1	A 1.1		A 1.1				A 1.1
48	L3			A 1.1	A 1.1		A 1.1				A 1.1
48	L4						A 1.1				
49	L1	A 1.2	A 1.2	A 1.2	A 1.2	A 1.2	A 1.2	A 1.2	A 1.2	A 1.2	A 1.2
50	L1	A 3.3	A 3.3	A 3.3	A 3.3	A 3.3	A 3.3	A 3.3	A 3.3	A 3.3	A 3.3
51	L1	A 1.2	A 1.1	A 1.2	A 1.3	A 1.2	A 3.1	A 1.2	A 1.2		A 1.3
51	L2	A 1.2	A 1.2	A 1.2	A 1.3	A 3.1	A 1.2	A 1.1	A 1.2	A 1.1	A 1.3
51	L3	A 1.1	A 1.2	A 1.2	A 1.3	A 1.2	A 1.2	A 1.2	A 1.2	A 1.1	A 1.3
52	L1	A 1.2	A 1.2	A 1.2	A 1.2	A 1.3	A 1.2	A 1.2	A 1.3	A 1.2	A 1.2
53	L1	A 3.3	A 3.1	A 3.3	A 3.3	A 3.2	B 1.2	A 3.2	A 3.1	A 3.3	A 3.3

**Table 3.1:**

*Fractures seen and classified by the five observers on CT and MRI readings.*



	GEN SURG		RADIOLOG		ORT. SURG		RESID 1		RESID 2	
	CT	MRI	CT	MRI	CT	MRI	CT	MRI	CT	MRI
A 1.1	3	6	6	8	1	14	1	1	5	5
A 1.2	23	20	12	11	13	9	29	20	14	13
A 1.3			7	8	5			3	3	8
A 2.1	1						1			
A 2.2		1	1					2		
A 2.3		1	7	4			1	17	1	
A 3.1	9	15	4	4	9	14	9		3	4
A 3.2	7	2	5	6	10	6	12	17	6	5
A 3.3	13	13	23	23	14	11	11		19	20
B 1.1								4		
B 1.2	2	9	3	5	8	11			4	5
B 1.3										
B 2.1	1								1	1
B 2.2							1	1		2
B 2.3	9		1	1	5	5			6	3
B 3.1										
B 3.2				1						
B 3.3										
C 1.1										
C 1.2						1				
C 1.3	1	1			3	1	1		2	2
C 2.1						1				
C 2.2									1	1
C 2.3										
C 3.1										
C 3.2			1	1						

**Table 3.2:**

*Frequencies of different fracture classes reported by the five observers on CT and MRI readings.*





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		GEN. SURG		RADIOL.		ORT. SURG		RESID 1		RESID 2	
		CT	MRI	CT	MRI	CT	MRI	CT	MRI	CT	MRI
GEN. SURG	CT	xxx	0.11	0.12	0.05	0.36	0.21	0.08	0.16	0.71	0.48
	MRI		xxx	0.33	0.61	0.27	0.38	0.12	0.58	0.28	0.29
RADIOL.	CT			xxx	0.41	0.30	0.15	0.25	0.40	0.34	0.23
	MRI				xxx	0.31	0.43	0.16	0.63	0.35	0.36
ORT. SURG	CT					xxx	0.66	0.19	0.26	0.60	0.57
	MRI						xxx	0.15	0.31	0.50	0.57
RESID 1	CT							xxx	0.30	0.20	0.21
	MRI								xxx	0.28	0.15
RESID 2	CT									xxx	0.76
	MRI										xxx

**Table 3.3:**

*Kappa values concerning the A / non-A distinction.*

		GEN. SURG		RADIOL.		ORT. SURG		RESID 1		RESID 2	
		CT	MRI	CT	MRI	CT	MRI	CT	MRI	CT	MRI
GEN. SURG	CT	xxx	0.12	0.14	0.06	0.38	0.23	0.10	0.10	0.72	0.50
	MRI		xxx	0.34	0.62	0.29	0.40	0.13	0.49	0.26	0.26
RADIOL.	CT			xxx	0.42	0.32	0.17	0.26	0.28	0.36	0.25
	MRI				xxx	0.32	0.44	0.17	0.54	0.31	0.32
ORT. SURG	CT					xxx	0.67	0.14	0.20	0.62	0.59
	MRI						xxx	0.11	0.26	0.48	0.55
RESID 1	CT							xxx	0.14	0.15	0.15
	MRI								xxx	0.22	0.09
RESID 2	CT									xxx	0.77
	MRI										xxx

**Table 3.4:**

*Kappa values concerning the Type categorization.*



		GEN. SURG		RADIOL.		ORT. SURG		RESID 1		RESID 2	
		CT	MRI	CT	MRI	CT	MRI	CT	MRI	CT	MRI
GEN. SURG	CT	xxx	0.70	0.47	0.50	0.61	0.65	0.56	0.59	0.66	0.61
	MRI		xxx	0.59	0.71	0.77	0.68	0.54	0.65	0.78	0.78
RADIOL.	CT			xxx	0.82	0.67	0.59	0.53	0.58	0.66	0.68
	MRI				xxx	0.80	0.71	0.56	0.62	0.79	0.81
ORT. SURG	CT					xxx	0.77	0.56	0.66	0.86	0.87
	MRI						xxx	0.58	0.66	0.75	0.66
RESID 1	CT							xxx	0.61	0.56	0.54
	MRI								xxx	0.58	0.58
RESID 2	CT									xxx	0.91
	MRI										xxx

**Table 3.5:**  
*Kappa values concerning the Type A Group distinction.*

		GEN. SURG		RADIOL.		ORT. SURG		RESID 1		RESID 2	
		CT	MRI	CT	MRI	CT	MRI	CT	MRI	CT	MRI
GEN. SURG	CT	xxx	0.45	0.36	0.33	0.38	0.23	0.41	0.29	0.51	0.36
	MRI		xxx	0.28	0.30	0.42	0.43	0.30	0.41	0.39	0.31
RADIOL.	CT			xxx	0.64	0.46	0.33	0.18	0.30	0.43	0.42
	MRI				xxx	0.35	0.29	0.16	0.24	0.42	0.52
ORT. SURG	CT					xxx	0.33	0.32	0.39	0.50	0.46
	MRI						xxx	0.33	0.30	0.32	0.27
RESID 1	CT							xxx	0.39	0.28	0.22
	MRI								xxx	0.22	0.21
RESID 2	CT									xxx	0.88
	MRI										xxx

**Table 3.6:**  
*Kappa values concerning the Type A Subgroup distinction.*



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GEN. SURG				RADIOL.		ORT. SURG		RESID 1		RESID 2	
		CT	MRI	CT	MRI	CT	MRI	CT	MRI	CT	MRI
GEN. SURG	CT	xxx	0.33	0.28	0.24	0.29	0.16	0.32	0.21	0.50	0.32
	MRI		xxx	0.26	0.32	0.34	0.36	0.25	0.36	0.31	0.28
RADIOL.	CT			xxx	0.57	0.36	0.25	0.16	0.28	0.34	0.33
	MRI				xxx	0.27	0.28	0.14	0.25	0.30	0.41
ORT. SURG	CT					xxx	0.33	0.26	0.31	0.50	0.44
	MRI						xxx	0.22	0.24	0.26	0.26
RESID 1	CT							xxx	0.35	0.23	0.18
	MRI								xxx	0.18	0.17
RESID 2	CT									xxx	0.79
	MRI										xxx

**Table 3.7:**

*Kappa values concerning the all three levels of the classification scheme.*

	INTER-OBSERVER CT	INTER-OBSERVER MRI	INTRA-OBSERVER CT/MRI
A / NON-A	0.08-0.71 (0.34)	0.15-0.63 (0.42)	0.11-0.76 (0.45)
TYPE	0.10-0.72 (0.35)	0.09-0.62 (0.39)	0.12-0.77 (0.41)
A GROUP	0.47-0.86 (0.61)	0.58-0.81 (0.73)	0.61-0.91 (0.76)
A SUBGR. SssSUBGROUP	0.18-0.51 (0.37)	0.21-0.52 (0.34)	0.33-0.88 (0.54)
COMPLETE	0.16-0.50 (0.31)	0.17-0.41 (0.28)	0.33-0.79 (0.47)

**Table 3.8:**

*Summary of the ranges of kappa values. In brackets generalized kappa values for inter-observer and mean kappa values for the intra-observer measurements.*

	A / NON-A		TYPE		A GROUP		A SUBGR.		COMPLETE	
	CT	MRI	CT	MRI	CT	MRI	CT	MRI	CT	MRI
ORT. SURG.	0.65	0.80	0.56	0.41	0.76	0.95	0.35	0.60	0.35	0.61
RESID. 1	0.29	0.30	0.28	0.32	0.62	0.77	0.40	0.40	0.60	0.35
RESID. 2	0.72	0.70	0.66	0.65	0.90	0.95	0.88	0.90	0.77	0.72

**Table 3.9:**

*Kappa values of intra-observer agreement of the three observers between the first and second CT and MRI readings.*



classification, the highest agreement on CT was achieved between the general surgeon and the resident 2, the lowest between the radiologist and the resident 1; on MRI readings the highest between the radiologist and the resident 2 and the lowest between the resident 1 and the resident 2. Considering both CT and MRI readings of all items, the highest average kappa was achieved between the orthopedic surgeon and the resident 2 and the lowest between the orthopedic surgeon and the resident 1.

Considering the distinction between Type A / non-Type A the inter-observer agreement was better with the MRI but reached only moderate levels. Agreement on complete Type division and division in all three levels were fair in both readings. The agreement over the group subdivision of the Type A reached a level of substantial agreement for both readings. The subgroup division of the Type A resulted also in fair agreement in both readings. The intra-observer agreements between the CT and MRI readings of the five observers were higher for all items but followed the same pattern.

In 30 fractures at least one of the observers reported a non-A fracture in one of his readings. For only one fracture there was a non-A categorization in all of the ten readings. For the CT readings, out of the 60 fractures reported by every observer, in 23 at least one of the observers reported a non-A fracture. Only in one case was there agreement among all observers on the non-A classification. For the MRI readings, 63 fractures were reported by all observers. In 26 of these at least one of the observers reported a non-A fracture. In two cases there was agreement between all observers on non-A categorization.

Kappa values for intra-observer agreement of the first and second CT and MRI of the three observers are shown in table 3.9. The highest kappa values were achieved by the resident 2 and the lowest by the resident 1. These values were as expected higher than the inter-observer agreements.

### 3.5 DISCUSSION

Fracture classification systems are useful conceptual tools for understanding the basic mechanisms involved. A classification system is based upon a presumption about an underlying common character-





istic of the subsets of a domain. In case of a fracture classification system this is based upon the presumption that the interaction of various forces with the parts of a living organism involved create some basic observable patterns. The main difficulty of all fracture classification schemes lies in the innumerable variables involved in a traumatic lesion. The classification has to presuppose an all or none result of some of the interactions.

In the case of thoracolumbar spine fracture classification scheme studied in our work the main determinant of the type categorization is the involvement of the posterior column. The classification presupposes that this complex is either injured or not. Although this distinction may be mechanically sound (Lange 1998), in reality we observed varying *degrees* of involvement of the posterior ligamentary complex. We observed different changes in the posterior ligamentary complex varying from slight edema to complete ruptures (Figs 3.1-3.5). Our operative findings were consistent with MR images as reported in other studies (Petersilge 1995, Terk 1997).

It is also by others observed that MRI's of fractures classified as compression fractures showed signs of posterior column involvement in almost 50% of the cases (Petersilge 1995, Saifuddin 1996, Terk 1997). In an experimental study it has been shown that MRI is capable of detecting ligamentary injuries associated with a fracture (Kliwer 1993). But it is not clear from the AO classification scheme which kind of soft tissue injuries should be seen as indicative of a non-A type injury.

Our study group is not an unselected population because of the fact that a number of patients with probably in the majority type B and C patterns are excluded due to the difficulties with advanced imaging within a week after trauma or before intervention. Inclusion of these patients would possibly result in higher kappa values in the distinction between A / non-A. But this does not explain the fact that in almost half of the fractures detected by every observer on both readings, at least one observer at least once doubted this major distinction. The designers of the scheme recognize these difficulties when they state that "it is quite natural that injuries occur which constitute transient forms between types... (a) type A injury can become type B when the degree of flexion exceeds the point beyond which the poste-



**Figure 3.1:**  
MRI of a fracture,  
which is classified as  
type A by all observers  
on both CT and MR  
readings.



**Figure 3.2:**  
This fracture is classi-  
fied as type A by all  
observers on CT  
reading and as type B  
by 2 observers on MR  
reading.

**Figure 3.3:**  
This fracture is  
classified as type B by  
one observer on CT  
reading and by four  
observers on MR  
reading.



**Figure 3.4:**  
This fracture is  
classified as type B by  
three observers on CT  
reading and by all  
observers on MR  
reading.





*Figure 3.5:  
One observer classified  
this fracture as type B  
on CT reading and  
two observers on MR  
reading.*

rior ligament complex definitely fails” (Magerl 1994). There is unfortunately no clue about how to define a “definitive failure” of this complex. The designers’ solution to this problem is: “Transient forms may either be allocated to the lesser or more severe category, depending on which characteristics predominate”. Although this might be the best strategy for an individual surgeon to decide over the treatment modalities, this ambiguity renders the scheme less reliable for comparison of patient populations from different locations. The designers also recognize that “some type B injuries ... were missed and classified as type A injuries when only standard radiographs are available”.

In a multi-layer classification scheme it is expected that the agreement rates decrease in subsequent levels as observed for the AO classification of peripheral fractures (Table 3.10). This does not seem to be the case in the classification scheme we studied. The agreement on the group classification of the common type A fractures was higher than the agreement on type categorization or A / non-A distinction. Subgroup classification, however, dropped, as expected, to lower values. This is another indication that the type categorization of the scheme is problematic. Although the inter-observer agreement on type A / non-type A distinction was higher with MRI readings in our study, it reached only moderate levels. Inclusion of MRI as a diagnostic tool may thus enhance the depiction of ligament injuries. But first



STUDY	INTER-OBSERVER	INTRA-OBSERVER
Ankle (Thomsen) Weber	0.57	0.68
Lauge Hansen	0.54	0.64
Pilon tibial (Swiontkowski)		
AO type	0.57	
group	0.43	
subgroup	0.41	
Tibial plafond (Dirschl)		
Rüedi-Allgöwer	0.43	
Distal tibia (Martin)		
AO type	0.60	0.70
group	0.38	0.48
Rüedi-Allgöwer	0.46	0.55
Prox. humerus Neer (Sidor)	0.50	0.66
Prox. Humerus (Siebenrock)		
Neer	0.40	0.60
AO type	0.53	0.58
group	0.42	0.48
Gustilo open fracture (Brumback)	0.60	
Evan's trochanteric fracture stability (Gehrchen)	0.41-0.77	0.69-0.77
Evan's trochanteric fracture stability (Andersen)	0.51	0.62
Distal radius Older (Andersen)	0.69	0.75

**Table 3.10:**  
Summary of some of the kappa values of fracture classification systems reported in the literature.

MRI findings should be described in a reproducible manner and should be integrated to the scheme. The kappa values with CT and MRI were comparable for all other parameters. Considering the potential of MRI to provide a better agreement on A / non-A distinction and no further advantage of CT we conclude that, as far as this classification is concerned, MRI can replace the CT as the diagnostic tool of choice for thoracolumbar spine fractures as suggested by others (Saifuddin 1996).







In its present form the type categorization of the scheme is not sufficiently reproducible to be used for comparison of different patient series. The inter- and intra-observer agreement on group and subgroup levels of the common type A fractures are comparable with reports in the literature of some common peripheral fractures (Table 3.10). The highest agreement was achieved on the type A group classification. But this is practically the same distinction between the “wedge-compression” and “burst” fractures of the older schemes (Denis 1983-a, Holdsworth 1963). This might be the only level at which high agreement can be expected with the present means of distinction.

Although intuitively one would think that inter-observer agreement between experienced observers and intra-observer agreement of more experienced observers would be better, earlier studies showed that this is not the case (Dirschl 1997, Martin 1997, Sidor 1993, Thomsen 1991). In our study the highest inter-observer agreement was between the orthopedic spine surgeon and one of the residents. One of the residents achieved also the highest intra-observer consistency.

A fundamental discussion about parameter definition in clinical orthopedic research is necessary. In table 3.10, kappa values for inter- and intra-observer agreements for some fracture classification systems are summarized. There is no consensus about the level of kappa values, which should be considered acceptable for fracture classification systems (Martin 1997). We used the distinction proposed by Landis and Koch as many of the other studies. However, in a recent editorial it has been suggested that fracture classification systems should have an inter-observer reproducibility level exceeding a kappa value of 0.55 (Sanders 1997). This would introduce very stringent criteria, which is probably not achievable in traumatology. From a skeptical point of view it can be argued that fractures are not reliably classifiable in any meaningful way. But it can also be argued that any degree of agreement higher than chance distribution can forward our common understanding of the patterns involved. “So is 1 per cent vision better than total blindness” (Dawkins 1991). In that case fracture classification schemes should be seen as evolvable entities of pattern recognition which should be subject to a continuous process of assessment, reassessment and refinement. A potentially serious com-



plication of such an evolving process however can occur in the increasingly popular instrument in clinical orthopedic research: the meta-analysis. For the sake of a possible future meta-analysis, authors are asked to convey their data according to schemes accepted in the literature. But without a proper appreciation of the inherent uncertainties of these schemes there is the danger of these meta-analyses leading to meta-errors.



**CORRELATION OF MR IMAGES OF DISC  
INJURIES WITH ANATOMIC SECTIONS IN  
EXPERIMENTAL THORACOLUMBAR SPINE  
FRACTURES**



**CHAPTER 4**

#### 4.1 INTRODUCTION

The role of intervertebral disc injury in the acute stability and long-term prognosis of thoracolumbar spine fractures is still poorly understood. The bony part in a vertebral fracture usually heals completely and returns to normal strength, but the healing of the relatively avascular disc is unpredictable and may depend on the pattern of sustained injury (Lin 1993, Oner 1998). This may partly explain the variations in the results of conservative treatment and the differences in failure rates of posterior fixation reported in the literature (Bednar 1992, Benson 1992, Cantor 1993, Denis 1983/b, 1984 Dickman 1994, Malcolm 1981, McCormack 1994, Mumford 1993/a, Speth 1995, Steindl 1992, Weinstein 1988, Willen 1985). Disc space narrowing has commonly been observed and has been associated with recurrent kyphosis as well as complications after posterior fixation (Akbarnia 1994, Andreychik 1997, Benson 1992, Esses 1989, 1991, Sjöström 1995, Speth 1995). A biomechanical study showed that about 60% of the acute hypermobility after a compression type fracture are situated in the surrounding discs (Lin 1993). Thus the failing disc may be a major contributor to chronic instability (Lin 1993, Oner 1998). The patterns of injury and healing of the discs are largely unknown. The functional integrity of the disc, however, do seem to effect the type of fractures in mechanical experiments and clinical observations (Hansson 1987, Shirado 1992). Especially in the common compression-type fractures, injury and healing patterns can be crucial in determining the outcome of non-operative treatment or posterior short-segment fixation. The AO classification system of thoracolumbar spine fractures (Section 2.2.5) also emphasizes the prognostic influence of soft tissue injury associated with fractures and separate discoligamentous injuries from osseous lesions (Magerl 1994). This classification system also makes some implicit assumptions about the integrity of the disc, based on indirect evidence from radiograms and CT scans. Mechanical studies showed that the anatomy of the fracture itself was the most important factor in the failure of posterior constructs (McCormack 1994). Based on these observations, a load-sharing classification has been devised with a good prognostic value (McCormack 1994). Inclusion of disc injury and healing patterns to this scheme can increase the predictive power of this classification





and help rationalize treatment regimens.

Conventional imaging modalities, however, are not capable of identifying disc injury patterns. Although MRI is a potentially useful tool to study the effects of different disc injury and healing patterns in clinical cases, it is not known whether it is possible to detect disc injuries associated with fractures. Frederickson et al (1992) used MR images for the study of distractibility of posterior fragment in a burst fracture model. They were able to image the posterior annulus sufficiently to study its relation to the reduction of the fragment with distraction. However, they did not specifically study the associated injuries of the whole disc. Therefore we designed this study to determine whether MRI is capable of detecting macroscopic injury to the disc in a cadaveric fracture model.

#### 4.2 MATERIALS AND METHODS

Thoracolumbar spine specimens obtained from ten fresh human cadavers without any macroscopic evidence of infectious or neoplastic disease were used. The average age of the specimens was 64 years (47-79). All muscles were removed with care, so as not to damage ligaments or facet joints. The thoracolumbar junctions with five to seven vertebrae, depending on the length of the spine, were removed. These specimens were fixed between two polyethylene cylinders filled with polyurethane, leaving one or two motion segments free. Anteroposterior and lateral radiographs and sagittal MR images of the specimens were obtained. The vertebrae and the discs were sequentially numbered from cranial to caudal. For MR imaging we used a 1.5 Tesla Philips Gyroscan ACS-NT. T2 SE (TR: 2200, TE: 22) and T2 TSE (TR: 1481, TE 106) sequences were used. T2 SE sequences were the same as used by Frederickson et al (1992); T2 TSE is one of the sequences used in our hospital in acute trauma cases. Fractures were created with a specially designed weight-dropping device with features allowing different weights and varying flexion angles. No attempt was made to standardize in any way the type of fractures, as we tried to create as many types of injury to the vertebral bodies and the discs as possible. Therefore we used varying weights and flexion angles in each of the specimens. After the injury, radiographs and MR images of the specimens were obtained with the



same sequences within the same day. Then the specimens were frozen at  $-20^{\circ}\text{C}$  in plastic bags to prevent drying. Sagittal sections of 5 mm were cut with a high-speed saw and photographed. To investigate whether this technique was adequate to detect all injuries, we used a more detailed analysis in two of the specimens. In these two specimens, multiplanar 3-D reconstructions were created with data obtained from volumetric MR acquisitions. For these two specimens a micro-cryoplaning technique was used to obtain sagittal sections of  $30\mu\text{m}$  (Leeuwen 1990). Each section was photographed and digitally recorded. Of these two specimens, slides at each 5-mm were collected on adhesive tape and stained with haematoxylin and eosin (H&E) to observe possible changes undetectable without staining.

Radiograms and MRI's of the specimens before and after the injury were evaluated by the radiologist. Pre-existent disc pathologies, fractures of the vertebral bodies, and changes in the discs between the first and second MRI's were described. Changes in the disc space were described as:

1. Ruptures through the anterior, middle or posterior 1/3
2. Herniation of the nucleus pulposus in the end plates
3. Changes in signal intensity in the disc space.

The first author, without access to the radiograms and MRI's evaluated the anatomical sections. The central one-third of the sagittal sections were used to identify:

1. Fractures of bony parts
2. Long standing degenerative changes in the discs
3. Schmorl's nodes
4. Ruptures through anterior and posterior annulus fibrosus or nucleus pulposus
5. Herniation of nucleus pulposus in the end plate
6. Debris in the disc space.

Finally during a joint session the findings on MRI's were compared with slides of the specimens.

#### 4.3 RESULTS

A total of 20 fractures were observed on anatomic sections (Table 4.1). In 12 of the discs adjacent to fractured vertebral bodies changes were seen on post-injury MR images in comparison with pre-





Specimen	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10
No. vert.	5	6	6	7	5	6	5	6	5	
Fract. vert.	3,4	3,4	5	3,4,5,6	3	3,5	2	2,3,4	3,4,5	3
Inj. discs	2,3	3	4	None	2	2,4,5	2	2	4	2
Disc 1	Pre-exis deg.	Pre-exis deg.	No injury	Pre-exis calcified	No injury	Pre-exis deg.	No injury	No injury	No injury	No injury
Disc 2	Rupture ant/cent	Pre-exis deg	Pre-exis Schmorl	Pre-exis deg.	Debris cent.	Debris cent.	Herniation in corpus	Debris cent.	No injury	Rupture ant.
Disc 3	Rupture cent.	Rupture ant.	No injury	Pre-exis deg.	No injury	Pre-exis deg.	No injury	No injury	No injury	No injury
Disc 4	No injury	No injury	Debris cent.	Pre-exis Schmorl	No injury	Rupture cent.	No injury	No injury	Rupture cent.	No injury
Disc 5	-	Pre-exis deg.	No injury	No injury		Rupture cent.			No injury	
Disc 6	-	-		No injury						

**Table 4.1:**

*Summary of the findings observed on the specimens. No. vert.: number of vertebrae included in the specimen; Fract. vert.: fractured vertebrae (the most cranial vertebra of the specimen is vertebra 1); Inj. discs: injured discs (the most cranial disc is disc 1). Ant., and cent. denote anterior and central 1/3 of the disc space. Ruptures denote fracture lines extending through disc space. Debris is substances from the bony endplate and the vertebral body within the confounds of the disc space.*

injury MR images. Fracture lines usually extended from the endplates into the disc spaces. These were seen as low-signal lines through the disc space on the MRI. We called these lines “ruptures” to prevent any confusion with fractures. Parts of the endplate or the cancellous bone from the vertebral body were sometimes seen to be thrown into the disc space. These were seen as low-signal artefacts in the disc space on the MR images. We called these “debris”. All of the changes seen between the pre- to the post-injury MR images corresponded to fresh injury to parts of the discs clearly discernible on anatomic sections. In discs, which remained unchanged between pre- to post-injury MR images, no evidence of fresh injury was found on anatomic sections. Most of the injuries were gross ruptures through the disc and were detected on all MR images. Even subtle changes on some of the discs which were seen on anatomic sections as staining of the



nucleus pulposus as a result of spraying of debris from the vertebral body following a minor fracture of the endplate, were detected on MR images as low-signal artefacts in the central part of the disc (Figs. 4.1, 4.2, 4.3). Some spontaneous reduction of the fractures was observed between post-injury MR images and the anatomic sections (Figs. 4.4, 4.5). All traumatic changes in the discs observed on the anatomical sections had been identified by the radiologist on the MR images. All changes identified on the MR images by the radiologist had been seen and reported on the anatomical sections. In the two specimens analyzed in detail through volumetric MR acquisitions and micro-cryoplaning technique no evidence was found for kinds of injury which would not be detectable with the usual MRI and anatomic sections. H&E stained sections did not reveal any other findings not seen on non-stained sections.

The injury patterns observed varied greatly. Many of the fractures resembled injuries observed in clinical cases. For example, specimen 4, belonging to a 79 years old lady with osteoporotic bone, showed four severe fractures of vertebral bodies without any injury to the adjacent discs. This pattern resembles clinical cases of osteoporotic fractures, with discs expanding into the fractured vertebral bodies. In specimen 7, from a 47 years old man, the injury created a fracture resembling an incomplete burst fracture (AO classification, A 3.1), with the disc herniated into the endplate, but remaining contained within the cartilaginous endplate. In specimen 3, a fracture of the endplate, which was hardly discernible on radiograms, was associated with spraying of debris in the disc space (Fig. 4.2). If this is a pattern occurring in patients, it may explain unexpected severe course after some minor fractures. In all specimens the more severe fractures of the endplate and the vertebral body occurred adjacent to non-degenerative discs, confirming the earlier clinical and experimental observations (Hansson 1987, Shirado 1992).

#### 4.4 DISCUSSION

Many types of injury to intervertebral discs are theoretically possible. If we consider the disc mechanism as consisting of the bony and cartilaginous endplates and a circumferential annulus, together containing a nucleus pulposus of mucoid material, we can imagine







**Fig 4.1:**  
*Specimen #3. T2 SE  
 midsagittal image  
 before injury.*

that this mechanism can be injured in many different ways. Different parts of this mechanism have probably different healing potentials. These factors may lead to variable modes of failure or healing. Bony endplate, which is the only structure detectable with conventional imaging techniques, may heal completely, but nevertheless lead to the disruption of the blood supply to the whole disc. The normal disc has an internal pressure higher than the surrounding tissues because of osmotic differences created by the composition of the nucleus pulpo-

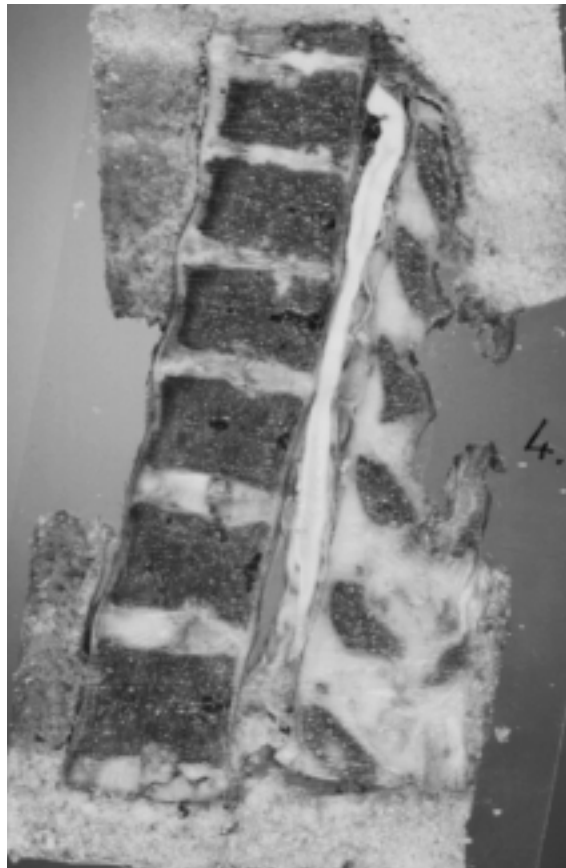


**Fig 4.2:**  
*The same specimen  
 after injury. The small  
 central endplate  
 fracture was hardly  
 discernible on  
 radiograms. Note the  
 low-signal area in the  
 nucleus pulposus of the  
 disc 4.*



sus. This creates an expansive force that is contained by the bony endplates and the annulus. This structure, with high expansive capacity, may creep into the defects in the endplate and expand itself into the vertebral body. Clinical observations support that this may be an important mechanism for explanation of the changes observed in the disc space after a fracture (Oner 1998). Another mechanism may be a rapid disc degeneration initiated by an annular tear.





**Fig 4.3:**  
Corresponding  
anatomic section of  
specimen #3. Debris  
from the vertebral  
body is clearly seen in  
the nucleus pulposus  
of the disc 4,  
corresponding to the  
low-signal area on the  
MRI.

Disruption of the annulus has been shown to lead to a rapid desiccation and degeneration of the whole disc in an animal model (Osti 1990). Finally, even if there is no change in the biological integrity of the disc, the changed morphology of the disc space as a result of the fracture of the vertebral body may alter its properties of resisting compressive forces. In a retrospective MRI study, Oner et al (1998) showed that all these different mechanisms may lead to different types of post-traumatic disc space changes, with possible consequences for the long-term stability of the injured segment. The question of



**Fig 4.4:**  
*Detail from the  
 cryosection of  
 specimen #6. The first  
 disc on this  
 photograph shows  
 debris in the central  
 area and a vertical  
 rupture through the  
 disc space. The second  
 disc is pre-existing  
 degenerative. The  
 third and fourth discs  
 show vertical ruptures  
 through the central  
 parts.*



whether these different mechanisms can be predicted from patterns of injury detected with MRI should be studied in a prospective fashion. Although this study showed an excellent correlation between macroscopic damage to the disc and its MR images, we should recognize that the reality in a living subject can be much more complicated. Microscopic damage not discernible on anatomic sections and MR





**Fig 4.5:**  
T2 TSE image of the same specimen. All changes seen on the anatomical sections are discernible. The second disc corresponds to the first disc depicted on the detail photograph in Fig. 4.4.

images or changes in the vascularity of the end plates can nevertheless have long-term consequences. Pre-existent changes in the discs such as Schmorl's or discopathy, which are in this study easily eliminated, will complicate the evaluation in clinical cases. Bleeding and edema may lead to changes absent in a cadaver study. With all these limitations in mind, we can nevertheless conclude that MRI gives a reliable image of macroscopic injury to different sections of the disc on clinically applicable sequences and can be used in prospective clinical studies to determine injury patterns and their long-term consequences. In our clinic we have been using the MRI for thoracolumbar spine fractures for some time, and our impression is that the images of



endplate and disc disruptions created in this cadaver study resembled very closely the MR images seen in clinical cases.

In an experimental study, Kliewer et al (1993) showed that injury to the ligaments associated with a thoracolumbar spine fracture can be reliably detected with MRI. Our study shows that the injuries to intervertebral discs and endplates can also be reliably detected with MRI. These studies justify the use of MRI in the acute phase for a detailed analysis of the injury patterns to structures undetectable with conventional imaging techniques, in order to investigate their possible prognostic consequences.

Recent attempts at sophistication of classification systems aim to achieve higher degrees of prediction (McCormack 1994, Magerl 1994). Inclusion of injury patterns of non-osseous structures and the load sharing capacity of the anterior column seem to be important aspects of the recent modifications of the classification systems to increase their prognostic power. Discs should be included in a comprehensive load sharing classification system, because of its mechanical and biological properties. MRI studies can be used for this purpose.



**MRI FINDINGS OF THORACOLUMBAR  
SPINE FRACTURES**  
A Categorization Based on MRI  
Examinations of 100 fractures



**CHAPTER 5**

## 5.1 INTRODUCTION

Thoracolumbar spine fractures are complex injuries of a structure, which is composed of parts with different susceptibility to injury and different healing potentials. This complexity is reflected in the difficulties with the classification attempts and in the confusion in the literature about the effectiveness of different treatment regimes. Remarkable differences in the long-term results of conservative treatment regimes or posterior stabilization methods have been reported in the literature (Bednar 1992, Benson 1992, Cantor 1993, Denis 1983/b, 1984, Malcolm 1981, Mumford 1993/a/b, Steindl 1992, Weinstein 1988, Willen 1985, Reid 1988). These difficulties are probably caused by inadequate definition of some of the essential prognostic parameters. Since Holdsworth, architectonic abstractions such as columns have been used to comprehend these complex injuries and their mechanical consequences (Holdsworth 1963). In the two-column spine of Holdsworth and the subsequent three column spine concepts of Louis (1977) and Denis (1983-a), the non-osseous structures of the spine were considered integral parts of these columns. The integrity of soft tissue structures, however, could only be inferred from indirect evidence from radiograms and later from CT scans. The most sophisticated classification system, which has been proposed to date, is the AO classification presented by Magerl et al (1994) (Section 2.2.5). In this scheme there are three main types of injury, defined by common morphologic characteristics and a common injury producing force. Extent and direction of soft-tissue injury are the main determinants of these types (Fig. 2.1). Type A injuries represent vertebral body compression caused by axial load with or without an element of flexion but without disruption of soft-tissues in the transverse plane. Type B injuries are anterior and posterior element injury with distraction, representing soft-tissue disruption in the transverse plane. Type C injuries are anterior and posterior element injuries with rotation. Each type is further subdivided into groups and subgroups using the common AO 3-3-3 grid (Fig. 2.2). The A 1 subgroup correspond to the "wedge fracture" and A 3 to the "burst fracture" of the Denis classification. The bony involvement in Type B and C fractures follows essentially the subdivision of the Type A fractures. The involvement of soft-tissues, which is the key determinant in type level of clas-







sification, was indirectly deduced from radiograms and CT scans in the original series of the authors (Magerl 1994). Although this scheme is very elaborate and allows a detailed analysis of the fractures, its relative complexity makes it prone to problems of reproducibility. A recent study showed poor reproducibility of the type level classification of this scheme with radiograms and CT's alone which somewhat improved with the use of MRI's (Chapter 3).

It is clear that many authors feel that soft tissue injury patterns are essential prognostic parameters. But these parameters have been poorly defined due to diagnostic difficulties. A reliable clinical examination of the soft tissue involvement is not possible in the thoracolumbar spine. Radiograms and CT's provide only indirect evidence of soft tissue involvement. MRI has been shown to be capable of depicting ligamentary injury associated with these fractures in clinical and experimental studies (Kliewer 1993, Petersilge 1995, Terk 1997). Petersilge et al reported on MRI's of 25 "burst fractures" according to the definition of Denis. They found in seven of the fractures posterior ligamentary disruption, which would be unsuspected on radiograms and CT scans. They also found rupture of the anterior longitudinal ligament in three fractures and rupture of the posterior longitudinal ligament in one. Terk et al report detection with MRI of posterior ligamentary complex injury in 36 of the 68 fractures studied. Another recent study showed the prognostic importance of changes in the disc space, especially in the conservatively treated patients, and classified these changes on MR images (Oner 1998). There are two cadaver studies, which showed excellent correlation between MR findings and anatomic sections. Kliewer et al (1993) showed in a cadaver study good correlation between MR images and anatomic sections of acute spinal ligament disruption. In a similar study Oner et al (1999/a) reported perfect correlation between MR images and anatomic sections of injuries to the discs and endplates. These studies establish MRI as a highly accurate modality for determining disco-ligamentary injury patterns and describe the MRI features of different structures involved. In their 1996 review article about the role of imaging in the diagnosis and management of thoracolumbar fractures, Saifuddin et al conclude that any future classification of thoracolumbar injuries should include MRI findings, allow-



ing assessment of the disco-ligamentary element of the injury as well as of the bony element (Saifuddin 1996). Our aim in this study is the determination of injury patterns observed on MRI's of patients with thoracolumbar fractures. We categorized MRI findings of structures involved in a fracture of the thoracolumbar spine that can have consequences for immediate and long-term mechanical stability of the spine. We also investigated the relation of these injury patterns observed on MRI's with the AO classification, which seems to be a suitable classification scheme for the integration of these findings.

## 5.2 MATERIALS AND METHODS

Since 1994 we have obtained MRI's of all patients with a thoracolumbar spine fracture admitted to our hospital. T1 (TR 578; TE 25), T2 (TR 2000; TE 100) and TSE (TR 2000; TE 30) images were obtained with a 1.5 Tesla Philips Gyroscan during the first week after admission. Images were always obtained in sagittal planes. In case of neurologic involvement, additional axial plane images were also obtained. MR imaging was not possible in case of polytrauma necessitating long periods of assisted ventilation or emergency intervention before imaging could be obtained. Patients with psychotic conditions were also excluded. All pathologic fractures including osteoporotic fractures were also excluded. MRI's were obtained for 70 patients. 100 fractures of the thoracal and lumbar spine (T3-L5) were observed in this group. The AO classification was used in our hospital during this period. All of these patients had been discussed in the weekly meetings of the spinal injury work group of our hospital consisting of orthopedic spine surgeons, general trauma surgeons, neurosurgeons and neuroradiologists. In these meetings, the injuries are classified according to the AO scheme by Magerl et al (1994) at the first 3 levels (Type, Group, Subgroup, i.e. A 3.1) using all available imaging data. According to these classifications 21 fractures were classified as A 1.1, 12 as A 1.2, 1 as A 2.3, 18 as A 3.1, 7 as A 3.2, 14 as A 3.3, 12 as B 1.2, 11 as B 2.3, 1 as C 1.2, 1 as C 1.3, and 1 as C 2.1. 36 patients with 61 fractures were treated conservatively, 33 patients with 38 fractures were treated operatively by posterior short segment pedicle screw constructs and one patient operatively by anterior Kaneda construct. During this study, the MRI's were available to the surgeons





who decided on the treatment options because we found it ethically unacceptable not to allow this.

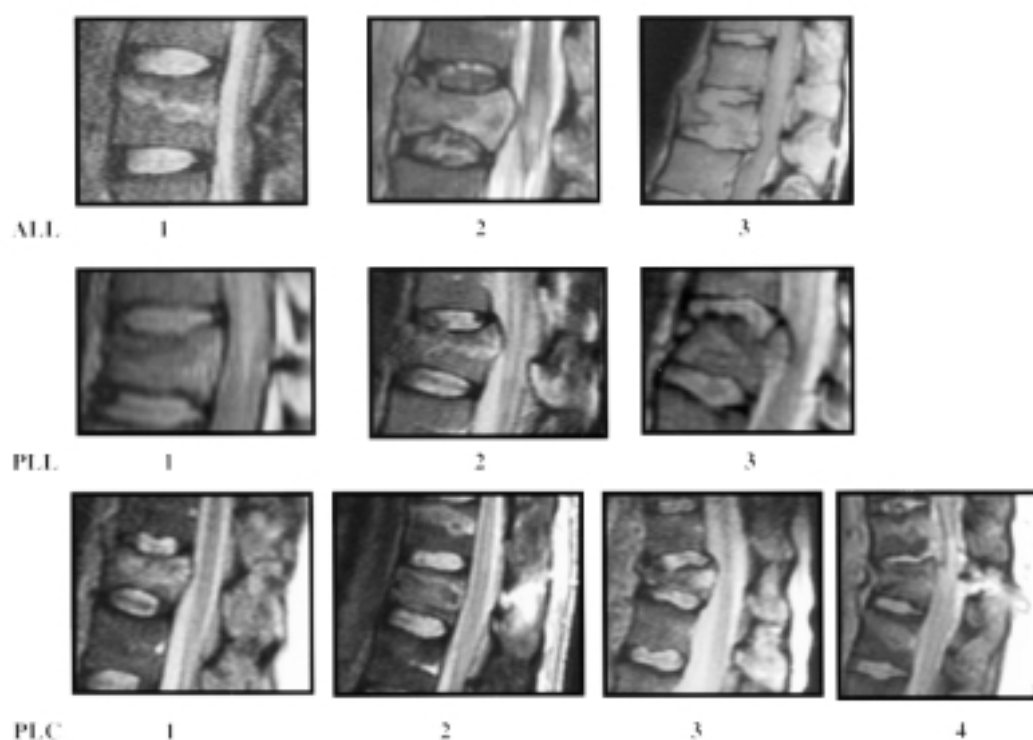
MR images of these 70 patients were collected and filed in an anonymous fashion blinded for all patient data. These files were evaluated in different rounds by one of the orthopedic spine surgeons and by the radiologist in order to recognize possible patterns. Using the information available from clinical and experimental studies, we reached a consensus about which structures could be important in the immediate and long-term mechanical stability of the spine, and for which there is sufficient data about reliable imaging with MRI. We finally decided that anterior longitudinal ligament, posterior longitudinal ligament, posterior ligamentary complex, cranial and caudal endplates and discs, and the vertebral bodies are structures which can be evaluated with the MRI, and which could theoretically influence the mechanical integrity of the spine. The first author developed the prototype of a scheme of different states of these structures. The radiologist and other members of our group evaluated this prototype until we reached a consensus on the definitive version of the scheme. We decided to limit this scheme only to the states of these structures. Other important parameters such as canal encroachment, neurological status or MRI evaluation of the dural sac and its contents can be separately combined with this scheme. We decided to call the various categories “states” because some imply no injury to the structure involved. These states were categorized on a scale of 1 to 4 in which state 1 represents no or minor injury with no mechanical consequences and higher grades implying higher probability of mechanical impairment. The final assignment to different categories was made during a joint session. This assignment was used for further analysis of the data.

The following scheme was accepted as the final version to classify the observed states of these structures (Figs 5.1, 5.2):

**Anterior Longitudinal Ligament (ALL):**

- **ALL 1:** No evidence of injury.
- **ALL 2:** The ligament is slackened but continuous. Either there is stripping of the ligament or as a result of bulging of the disc and the anterior portion of the endplate the ligament is no more tight.

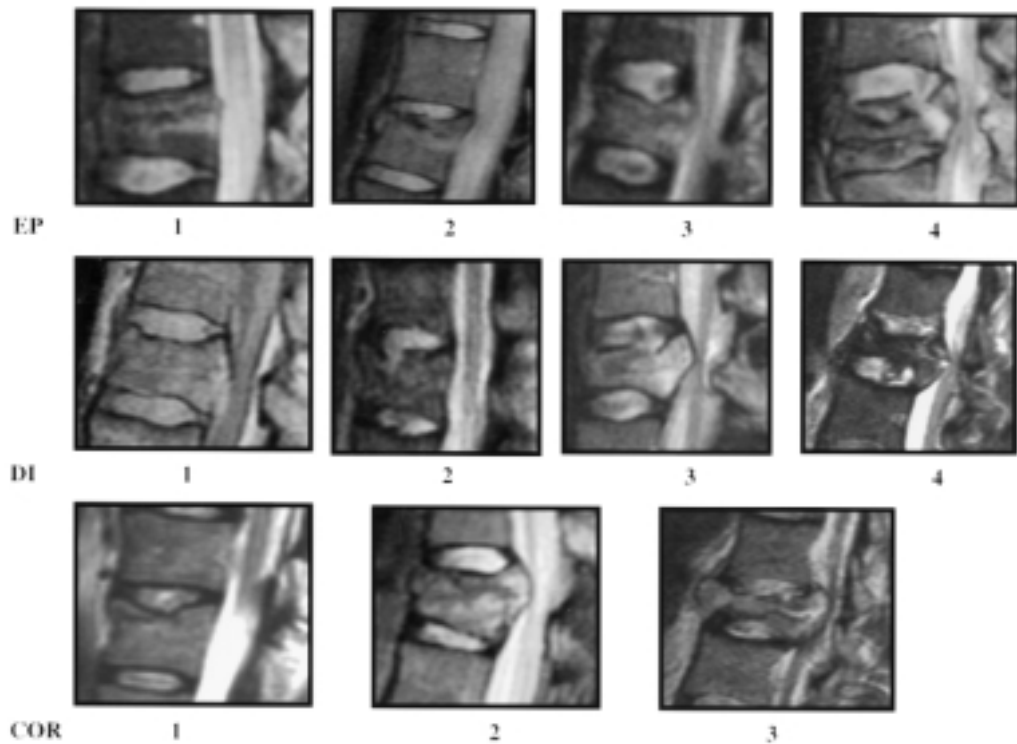




**Figure 5.1:**  
States of the  
ligamentary structures  
observed on the MRI's.  
ALL: Anterior  
Longitudinal  
Ligament; PLL:  
Posterior Longitudinal  
Ligament; PLC:  
Posterior Ligamentary  
Complex.

- ALL 3: The ligament is ruptured.
- Posterior Longitudinal Ligament (PLL):**
- PLL 1: No evidence of injury.
- PLL 2: The ligament is attached to the extruding bone fragment from the posterior cortex and continuous.
- PLL 3: The ligament is ruptured
- Posterior Ligamentary Complex (PLC):**
- PLC 1: No evidence of injury.
- PLC 2: Edema in the interspinous space without evident discontinuity or elongation.
- PLC 3: Elongation of the interspinous space without evident discontinuity. This elongation is assigned to a higher category because it probably implies a certain weakening of resistance against distraction forces while edema may occur in a more





structurally intact ligament.

→ **PLC 4:** Clear disruption of the PLC.

**Endplate (EP):** Cranial (EP CR) and caudal (EP CA) endplates are evaluated separately.

→ **EP 1:** Only plastic deformity of the endplate. No disruption.

→ **EP 2:** Disruption in the anterior half of the endplate. Evident discontinuity of the low signal (black) line of the endplate is necessary to call it a discontinuity. Pre-existent changes such as old fractures or Schmorl's nodes can be eliminated in this way.

→ **EP 3:** Disruption in the posterior half of the endplate. This is assigned to a higher category because it implies a certain instability in the direction of the neural canal.

→ **EP 4:** Disruption of the whole endplate.

**Figure 5.2:**  
States of the end-  
plates, discs and ver-  
tebral bodies observed  
on the MRI's. EP:  
Endplate; DI:  
Intervertebral Disc;  
COR: Corpus  
(Vertebral body).



**Disc (DI):** Cranial (DI CR) and caudal (DI CA) discs are evaluated separately.

- **DI 1:** No evidence of injury in the disc space.
- **DI 2:** Rupture and/or debris in the anterior half of the disc space.
- **DI 3:** Rupture and/or debris in the posterior half of the disc space.
- **DI 4:** Involvement of the whole disc. Either the disc is completely herniated into the vertebral body and/or there is rupture and debris in the whole disc space.

**Vertebral Body (COR):**

- **COR 1:** Less than 1/3 of the volume of the vertebral body is involved. The involvement of the body is evaluated using the amount of bone marrow edema as a measure of involvement.
- **COR 2:** 1/3 to 2/3 of the volume of the vertebral body is involved.
- **COR 3:** More than 2/3 of the volume of the vertebral body is involved.

### 5.3 RESULTS

A wide variation of injury patterns was observed. The frequency of different states of the eight parameters for the whole group is shown in Fig. 5.3.

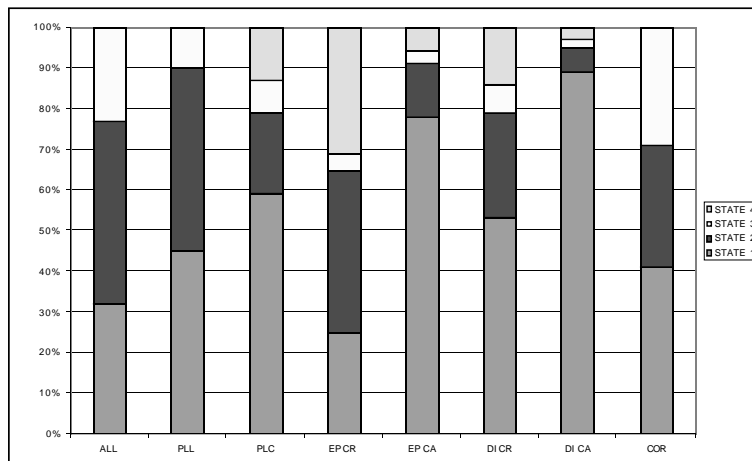
These results showed a quite confusing picture, in which we were not able to define any patterns of the MRI parameters, which could correspond readily to categories of different existing classification systems. Although originally our aim was to define MRI findings of fractures classified according to existing schemes, we realized that this was not to accomplish easily because of the wide variations of different combinations of the parameters observed.

#### 5.3.1 RELATION OF THE MRI FINDINGS WITH THE AO CLASSIFICATION

We decided to investigate systematically the relation between the MRI parameters and the classification scheme by Magerl et al (1994). There were several reasons why we chose this scheme to test our categorization:

- this scheme takes into account the effects of forces or moments





**Figure 5.3:**

*Frequency of different states of the parameters studied. ALL: Anterior Longitudinal ligament; PLL: Posterior Longitudinal Ligament; PLC: Posterior Ligamentary Complex; EP CR: Endplate Cranial; EP CA: Endplate Caudal; DI CR: Disc Cranial; DI CA: Disc Caudal; COR: Vertebral Body.*

which have acted on the spine during injury and is therefore a mechanistic classification;

- emphasizes the extent of involvement of soft-tissue injuries;
- is comprehensive in its effort to create a framework for a detailed registration of the parts of the injured segment, which may play an important role in the acute mechanical, neurological and long-term stability;
- has a logical, hierarchical structure, which can allow to create an evolvable pattern-recognition process and therefore can be used as a basis to integrate the MRI findings;
- We have been using this scheme since 1995, so that we are aware of the possibilities and difficulties of the scheme.

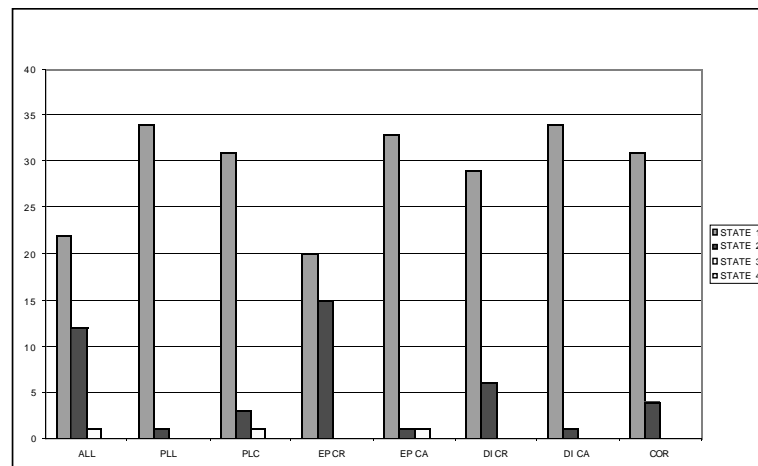
We first tried to match MRI findings with the classifications reported in the patient charts:

**Type A 1.1:** (N=21). All of these fractures were seen in combination with other fractures at other levels. In three of these fractures the ALL 2 was seen, the rest being ALL 1. PLL and PLC were State 1 in all cases. EP CR was in five fractures State 2 the rest State 1. EP CA, DI CR and DI CA were State 1 in all cases. In only one fracture the COR was State 2, all the rest being State 1.

**Type A 1.2:** (N=12). In four of them the PLC was State 2 or 3. The other parameters showed a wide variation.



**Figure 5.4:**  
Distribution of the  
MRI parameters for  
fractures classified as  
A1.



**Type A 2.3:** (N=1) This fracture had the following parameters: ALL 2, PLL 1, PLC 1, EP CR 2, EP CA 1, DI CR 2, DI CA 1 and COR 1.

**Type A 3.1:** (N=18). In five of the fractures the ALL was State 3, in two PLL was State 3 and in three fractures the PLC was State 2 and in one State 3. Endplate, disc and corpus involvement showed variations.

**Type A 3.2 and A 3.3:** (N=7 and N=14 respectively). These two were considered together. ALL 3 was seen 9 times. PLL 3 was seen once. Once the PLC was classified as State 4, three times State 3, four times State 2 and 13 times State 1. Wide variation is seen in the distribution of other parameters.

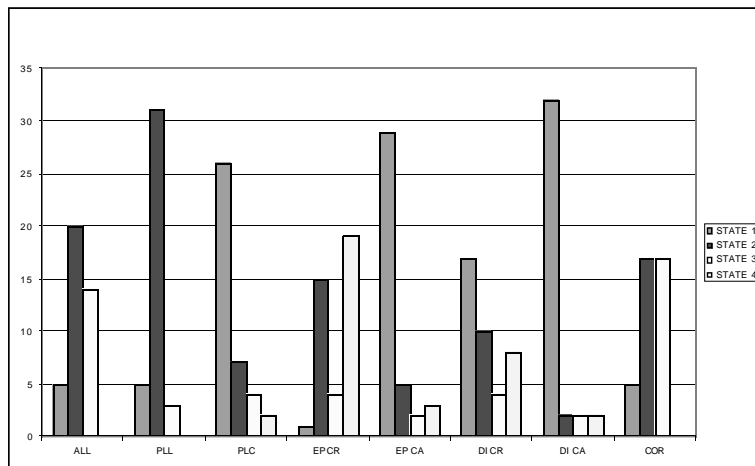
**Type B:** There were 12 B1.2 and 11 B2.3 fractures. ALL was State 3 in 6 of them. 11 times PLC was State 4, three times State 3, 9 times State 2. Other parameters showed variations.

**Type C:** Three fractures were classified as such. ALL 3 was seen twice and ALL 2 once. PLL was State 2 twice and State 1 once. PLC was once 4, once 2 and once 1. EP and DI parameters showed variations. COR parameter was twice State 3 and once State 1.

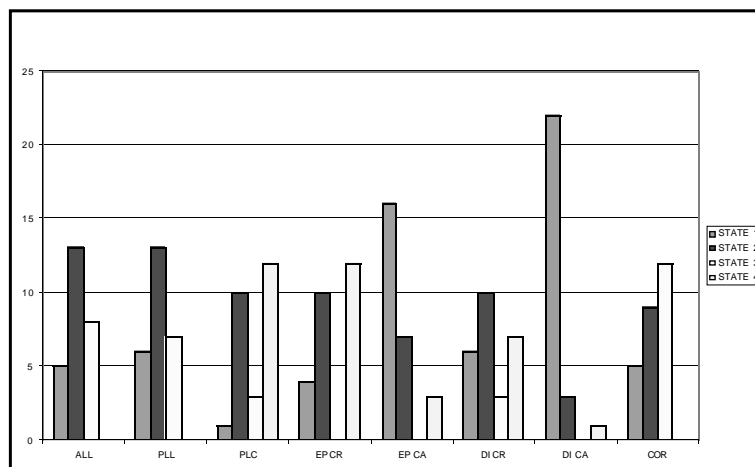
Distribution of MRI parameters in fractures, which had been classified as A 1, A 3 and B and C types, is represented in Figs. 5.4, 5.5 and 5.6. As can be seen on these charts, variations in many parameters within the same category are encountered.







**Figure 5.5:**  
*Distribution of the MRI parameters for fractures classified as A3.*



**Figure 5.6:**  
*Distribution of the MRI parameters for fractures classified as type B or C.*

Using the detailed description of the AO classification provided in the article of Magerl et al (1994), we tried to formulate which of our MRI parameters would be allowable in different categories of the classification. Beginning with the first (Type) level of the classification scheme, the main distinction is between on the one hand the Type A injuries



and on the other hand Type B and C injuries. According to the description of the classification scheme the major distinction between these Types is the presence or absence of transverse disruption. While Type A injuries result from compression forces alone, in Type B injuries there are also tensile forces causing transverse disruptions and in Type C injuries there are also torque forces causing rotational displacements in transverse plane. Posterior column involvement is seen as the crucial parameter in the distinction between Type A injuries on the one hand and Type B and C injuries on the other. Our PLC (posterior ligamentary complex) parameter seems to correspond to the posterior column involvement of the AO scheme. However, it is not clear from the scheme whether PLL involvement is also a necessary condition to diagnose transverse disruption. Our PLC parameter contained four categories. PLC 1 is no evidence of injury and PLC 4 is complete disruption. PLC 2 and PLC 3 represent transitional forms with partial involvement. We feel that it is safe to consider these two categories as indicative of posterior column involvement as no data is available about the mechanical integrity of the posterior column in such cases. But it can also be argued that only PLC 4 represents an indisputable transverse disruption. The state of the PLL can also be seen as a crucial element in the resistance against tension forces and as such a necessary component of transverse disruption. If we accept PLC categories 2, 3 or 4 as sufficient conditions to classify an injury as non - Type A (Type B or C), 44 fractures would be non - Type A. If we consider PLL 3 also necessary, then only 14 fractures would classify as such. If we accept only PLC 4 as the necessary condition, 10 fractures would classify as non - Type A. If we consider PLC 4 and PLL 3 as necessary conditions, only 4 fractures would classify as such. These calculations exemplify the difficulties encountered if we try to define the MR images of different categories of the classification scheme.

Accepting that PLC 2, 3 or 4 is sufficient to classify an injury as non - Type A we tried to formulate which categories of the MRI parameters would be allowable in different fracture classes of the AO classification on the first three levels for the Type A and Type B fractures. This formulation is shown in table 5.1. As is seen here, the result is wide variations in different MRI categories and various combinations of





CLASS AO	ALL	PLL	PLC	EP CR	EP CA	DI CR	DI CA	COR
A1.1	1,2	1	1	1	1	1	1	1
A1.2	1,2	1	1	2	1	1,2	1	1
A1.3	1,2	1	1	1	1	1	1	3
A2.1	1,2	1,2	1	2,3	2,3	2,3	1,2,3	2,3
A2.2	1,2	1,2	1	2,3	2,3	2,3	2,3	2,3
A2.3	2,3	1,2	1	4	4	4	2,3,4	3
A3.1	2,3	2,3	1	2,3,4	1	1,2,3,4	1	1,2
A3.2	2,3	2,3	1	2,3,4	2,3	1,2,3,4	1,2,3	2,3
A3.3	2,3	2,3	1	2,3,4	2,3,4	1,2,3,4	1,2,3,4	3
B1.1	1	2,3	2,3,4	1	1	1	1	1
B1.2	1,2,3	1,2,3	2,3,4	1,2	1	1,2	1	1
B2.1	1	3	2,3,4	1	1	1	1	1,2
B2.2	1,3	2,3	2,3,4	1	1	4	1	1
B2.3	2,3	2,3	2,3,4	2,3,4	1,2,3,4	1,2,3,4	1,2,3,4	2,3

**Table 5.1:***MRI parameters allowable in different AO classes.*

these categories in the same fracture class. When we reclassified the fractures using this scheme fifteen fractures had to be reallocated from Type A to Type B injuries and one fracture from Type B to Type A.

### 5.3.2 SURGICAL FINDINGS

33 patients with 38 fractures were treated operatively through a posterior approach. 15 of these fractures had PLC 1, 11 PLC 2, 3 PLC 3 and 9 PLC 4. In all of the fractures in which the PLC was categorized as state 4, extensive rupture of the interspinous ligaments, ligamentum flavum and facet joint capsules were found. In fractures with MRI's categorized as PLC 2 partial ruptures of the interspinous ligaments with edema and hematoma were found. In some of the cases there were also partial ruptures of the facet joint capsules. In three of the fractures with on the MRI's PLC category 3 was seen the interspinous ligaments were stretched but there was no evident discontinuity. In two of these fractures we observed rupture of facet joint capsules. In the patient operated through anterior approach the states of the ALL 1 and PLL 3 were confirmed.



#### 5.4 DISCUSSION

The MR findings of thoracolumbar spine fractures categorized in this study show a wide variation. Many of the findings could not be inferred from conventional radiograms and CT scans and are not accounted for by the existing classification schemes. We agree with other authors that posterior column involvement is much more common than previously believed (Petersilge 1995, Terk 1997). High frequency of ALL rupture (23%), which was also reported by Petersilge et al in a small number of patients, is an unexpected finding. These injuries may be caused by a rotational or shear component of the injury producing force or by the outward expanding force created by the bursting out of the vertebral body or the disc. Complete rupture of the PLL was seen in 10 fractures. In 8 of them the PLC was also completely ruptured. But in 5 cases with ruptured PLC the PLL was intact. In some cases The PLL rupture is probably caused by the flexion moment creating a Type B injury. But in others it can be caused by the forces created by bursting out of the endplate or the disc. The integrity of the PLL is especially important for indirect reduction of the fragments encroaching the canal. Long term effects of other ligamentary injuries are probably neutralized by an operative treatment. Unrecognized ligamentary injury in conservatively treated patients, however, may be responsible for some of the complications such as progressive deformity or persistent pain. Different injury patterns of the endplates and intervertebral discs together with the amount of vertebral body involvement may together determine the load-sharing capacity of the anterior column both in the acute phase and in the long term. McCormack et al (1994) developed a load-sharing classification of the anterior column using CT images with which they could predict failure of posterior short segment constructs. In a retrospective MRI study Oner et al (1998) showed the importance of the changes in the disc space for progression of kyphosis in conservatively treated patients and the recurrence of kyphosis in posteriorly stabilized fractures. They conclude that in the majority of cases this happens not through a frank disc degeneration process but through a failure of the endplate by the distension and creeping forces of the disc. In this study it proved difficult to establish the relation of MRI findings with the existing classification systems. All existing classification





systems are theoretical constructs based on the patterns observed on radiograms and CT images. The states of many structures are inferred indirectly from these images. We investigated in this study the relation of direct images of these structures with the indirect theoretical models. Because of its elaborate system, which also consider the state of the ligamentary structures, we thought that the AO classification scheme would be a good candidate to integrate the MRI findings in. Although it seems possible to define the different Types, Groups and Subgroups of the AO classification using our scheme, this classification does not capture all the variations in the parameters defined (Table 5.5). It is not clear from the classification scheme what would be the exact state of all the structures involved. Even the most basic level of the classification scheme, distinction between Type A and non - Type A, poses serious difficulties when we try to define it on the hand of the MRI findings. It might be necessary to devise new classification systems based on the MR images. We agree with Saifuddin et al (1996) that any future classification of thoracolumbar injuries should include MRI findings. Our categorization scheme can be used for this purpose.

Verification of our findings is not complete. Although experimental studies showed good correlation between the injuries and MRI's, it is preferable to verify them by surgical findings. Because our preferred method of treatment is a posterior approach, we could only verify the categories of the posterior structures. If other clinics that use more often anterior approaches adopt our scheme, it should be possible to verify other parameters as well.

The major differences in the literature in the outcomes of similar conservative treatment regimes are probably a result of variations in some of the parameters involved. There was no way to get two comparable patient populations without an adequate description of all the relevant parameters. With the parameters defined on MRI it will be possible to develop prognostic criteria in prospective studies. This is the only way to resolve the controversy as to whether to treat patients conservatively or operatively, which has become more of a cultural difference than of scientific knowledge. These prognostic criteria may help prevent complications in conservative treatment and unnecessary long recumbence or unnecessary operations. The same is true in



the choice between posterior and anterior operative approaches. If failure of posterior constructs can be predicted reliably, unnecessary extensive anterior approaches with a high morbidity could be avoided (Dickman 1994).

The patient population in this study is being followed up according to a protocol consisting of radiological and clinical parameters, which hopefully will lead to answers to some of these questions. But definitive answers can only be expected from larger populations from different clinics. Routine use of MRI and adoption of the scheme presented in this study would facilitate standard data accumulation and create comparable groups with sufficiently described lesions.



**RECURRENT KYPHOSIS AFTER  
POSTERIOR STABILIZATION OF  
THORACOLUMBAR FRACTURES**  
24 cases treated with a Dick internal  
fixator followed for 1.5-4 years



**CHAPTER 6**

## 6.1 INTRODUCTION

Pedicle screw instrumentation makes it possible to reduce thoracolumbar burst fractures over a short segment. This seems to be biomechanically advantageous (Aebi 1987, Dick 1987, Broom 1989, Esses 1989, 1991, An 1991, Ebelke 1991, Lindsey 1991, Bednar 1992, Benson 1992). However, the results of a short-segment posterior stabilization are not always good. Recurrent kyphosis with or without material failure has been reported (Matsuzaki 1990, McAfee 1991, West 1991, McLain 1993, Sasso 1993, McCormack 1994). Determination of factors, which predict the failure of posterior stabilization, would be helpful in determining which patients need a more extensive procedure. We have therefore retrospectively analyzed a group of 24 patients with burst fractures at the thoracolumbar junction, managed with a Dick internal fixator.

## 6.2 PATIENTS AND METHODS

24 patients with a traumatic fracture of the thoracolumbar junction of Th12 or L1 managed with a Dick internal fixator between 1986 and 1991 in 3 University Hospitals (Leiden, Utrecht and Rotterdam) were studied (Table 6.1). 1 patient (case 10) had also a burst type L4 fracture, which was treated with a second internal fixator, and another patient (case 15) had an L3 compression fracture, which required no additional treatment. There were 12 women and 12 men with 7 Th12 and 17 L1 fractures. The average age of female patients was 37 (15-67) and of male patients 26 (17-43) years. Pre-operative plain radiographs and CT-scans were available for all patients. The indications for operation accorded with the Denis et al. (1984) classification. 2 fractures were classified as having instability of first degree (cases 1 and 5) and 22 of second degree. 12 fractures were unstable according to the classification of Louis (Louis 1977). In 10 patients with complete or partial neurological impairment, an intracanal posterolateral reduction of compressing fragments was performed through a partial laminectomy. All of the patients except 6 were operated on within 1 week of trauma. In cases 2, 3, 18, and 22, there was a delay because of cerebral lesions or cardiopulmonary instability and cases 1 and 14 were referred to us later. Reduction technique, as described by Dick, was used in all the cases. A posterior





# RECURRENT KYPHOSIS



A	B	C	D	E	F	G	H/a	H/b	H/c	I/a	I/b	I/c	J
1	32	2	4	1	0.5	0	16	12	18	22	21	40	3
2	48	1	2	4	2	2	30	7	17	34	7	32	1
3	19	2	2	4	2	2	13	15	13	9	10	14	0
4	21	1	1	5	2	0	23	18	17	23	21	25	1
5	33	2	4	2	0.5	0	34	10	14	30	5	14	0
6	52	1	1	3	1.5	1	20	11	9	13	5	7	0
7	22	2	4	4	2.5	3	22	15	18	22	1	9	0
8	28	2	4	4	2.5	3	13	4	6	14	10	8	1
9	41	2	4	4	2.5	3	14	6	6	14	3	2	0
10	39	1	3	4	2.25	4	19	10	12	18	2	28	2
11	50	1	2	5	2.25	0	8	0	1	13	1	12	0
12	19	2	2	4	1.5	0	14	9	11	8	4	24	1
13	17	2	1	4	2.25	3	28	28	27	30	26	30	1
14	67	1	2	3	1.5	0	4	5	21	8	6	31	1
15	21	2	2	4	1.5	2	30	22	20	31	18	32	1
16	19	1	3	4	2.5	0	27	10	22	15	10	20	1
17	15	1	3	4	1.5	4	28	14	16	28	7	20	1
18	43	1	2	4	1.5	4	18	17	20	23	18	33	1
19	44	1	2	4	2	0	28	8	13	19	4	13	1
20	20	2	2	4	1.5	0	15	12	12	4	10	20	1
21	27	1	3	3	2	4	32	30	34	20	12	40	1
22	43	2	3	4	1.5	4	26	8	9	9	9	13	2
23	18	1	2	4	2	3	25	8	10	21	5	2	0
24	17	2	4	4	2	0	24	17	17	17	14	20	0

**Table 6.1:**

*General data concerning patients:*

**A Case**

**B Age**

**C Sex:** 1 female; 2 male

**D Cause:** 1 road accident; 2 fall; 3 attempted suicide; 4 industrial accident.

**E Type Denis:** 1 1A; 2 1B; 3 2A; 4 2B; 5 2E

**F Stability based on the Louis points of instability (0-3). Unstable if  $k \geq 2$**

**G Neurology:** 0 no injury; 1 cerebral commotion; 2 cerebral contusion; 3 paraplegia; 4 conus syndrome

**H Anterior compression angle (W):** /a preoperative; /b postoperative; /c last measured

**I Kyphosis angle (K):** /a preoperative; /b postoperative; /c last measured

**J Patient satisfaction:** 0 excellent; 1 good; 2 fair; 3 poor



spondylodesis between 3 vertebra was performed, except in cases 14, 17, 19, and 20. In 12 patients (cases 1-12) additional transpedicular autologous spongiosaplasty of the fractured vertebra was performed (Daniaux 1986, 1991, Dick 1987). Within 2 weeks after the operation, patients were allowed to stand or sit in a molded thoracolumbar orthosis or a brace, which was worn for about 3 months. In 5 patients with complete and non-resolving paraplegia, the fixator was not removed. In the others, the fixator was removed after a minimum of 1 year.

At 35 (18-48) months follow-up, all the patients were examined by persons not involved in the treatment. Standing or sitting AP and lateral radiographs were obtained. Patient satisfaction was evaluated during an interview. All radiographs and CT's were reviewed. Anterior compression angle (wedge W) of the fractured vertebra and local kyphosis (K) angles between the vertebrae above and below the fracture were measured according to Denis et al. (1984). Fractures were also classified according to Louis. Posterior cortex height (PCH) of the vertebral body as a percentage of that of the caudal vertebra was measured as described by Aebi (1987). Descriptive statistics and t-tests were performed using SPSS/PC+, version 5.0.1. The two-sample t-test was used to test differences between groups.

### 6.3 RESULTS

There was one deep infection (case 3) and removal of the implant was necessary 5 months after the operation. This patient was further managed with a cast and the infection resolved. No neurological complications were associated with the operations. In 4 cases (2, 10, 15, and 21), some of the transpedicular screws fractured. In case 21, both cranial screws were broken within 6 weeks after the operation. The fixator was replaced, but the new screws fractured after 6 months. In cases 1 and 12, screw migration was observed without material failure. In 12 cases (1, 2, 10-12, 14-18, 20, and 21), we observed a 10 degrees or more increase in the K-angle during the follow-up period. In only 3 of them was there an accompanying 10 degrees or more increase in the W-angle (cases 2, 14, and 16). Loss of PCH was observed in cases 2 and 14. 1 patient found the result poor and two patients considered it fairly good. The rest were satisfied.





	GROUP A		GROUP B		95% conf.
	Mean	SD	Mean	SD	interval
A	34	12	29	16	-8/17
B	19	8	24	8	-12/3
C	18	8	19	9	-9/7
D	9	7	8.8	8	-7/7
E	11	10	7.2	8	-5/12
F	2	5	3.5	5	-6/3
G	10	10	11	9	-10/8

**Table 6.2:**

*Statistical analysis of the evolution of W- and K- angles in group A (additional transpedicular spondioplasty) and group B (no transpedicular spondioplasty).*

**A Age**

**B W-angle preoperatively**

**C K-angle preoperatively**

**D Correction of W-angle (difference between, post- and preoperative values)**

**E Correction of K-angle (difference between post- and preoperative values)**

**F Loss of correction of W- angle (difference between last measured and postoperative values)**

**G Loss of correction of K- angle (difference between last measured and postoperative values)**

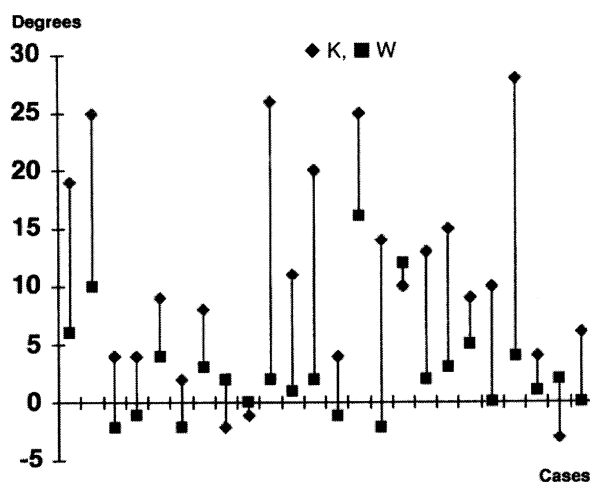
We compared patients with (group A: cases 1-12) and without (group B: cases 13-24) a transpedicular spondioplasty (Table 6.2). For none of the preoperative variables there was a statistically significant difference between the 2 groups. We consider the possible differences, as indicated by the confidence intervals, too small to invalidate our comparison of the results.

In group A, the preoperative mean W- and K-angles were each 19° and postoperatively these were reduced to 10° and 8°, respectively.

The PCH was corrected from a mean of 84 to 95 percent and remained the same during the follow-up in all, except case 2 who also had an increase of 10° in the W angle. In 5 cases (1, 2, 10, 11, and 12) there was a 10° or more increase in the K-angles, 4 of which had complications (cases 1 and 12 had screw migration and cases 2 and 10 screw fracture).



**Figure 6.1:**  
Change in K- and W-  
angles (difference  
between the last mea-  
sured and direct post-  
operative values).



In group B, the pre-operative mean W-angle was 24° and the K-angle 19°, and post-operatively these were reduced to 15° and 12°, respectively. The PCH was reduced from a mean of 87 to 93 percent, and remained the same at a mean of 90 percent, except in case 14. A 10° or more increase in the W-angle was observed in 2 cases (14 and 16). 7 cases (14-18, 20, and 21) showed a progression of the K-angle of 10° or more and 2 of them had complications (screw fracture in cases 15 and 21).

The difference in the degree of the K-angle or W angle reduction between the two groups was not significant (Table 6.2). The difference in the increase of the K-angle or W-angle during the follow-up was not significant either. In the whole group there was no correlation between the instability scores, according to Denis or Louis (p 0.8 and p 0.6), or the amount of reduction in the K- or W-angle (p 0.9 and p 0.1, respectively) with the final increase in K- or W-angle. There was no significant difference in subjective evaluation between the 2 groups (p 0.2). The difference in increase in the W-angle or the K-angle between the group of 10 patients who underwent a decompression and the other patients was not significant (p 0.3 and p 0.5, respectively).

For the whole group, the average increase in the K angle was higher than that in the W-angle (Figure 6.1). This difference was highly sig-





nificant (one-tailed t-test with  $H_0$  no difference,  $p$  0.001).

Concerning the 3 patients with a  $10^\circ$  or more increase in the W-angle, case 14 was a 67-year-old woman with osteoporotic bone and case 16 was a 19 year-old woman with primary hyperprolactinemia. The third patient (case 2) was a 48-year-old woman who had been lost to follow-up until she was called back for this study 2 years after the operation. 2 of these patients (cases 2 and 14) were also the only ones in whom a loss of PCH was observed.

#### 6.4 DISCUSSION

Extent of bone comminution has long been regarded as a major determinant of the success of posterior stabilization in burst fractures. Louis based his classification on the stability of bony structures. Recently, there was a new attempt to classify bone comminution with emphasis on the load-sharing characteristics of the fractured vertebral body (McCormack 1994). However, as shown by the experimental study by Lin et al. (1993), the bony lesion is responsible for less than half of the posttraumatic instability, the remainder being caused by non-osseous structures, including the intervertebral discs. As one might expect a rapid union of the cancellous bone after a comminuted fracture the discs may be the main cause of chronic instability (Lin 1993). In our group there was no correlation between the Louis score and the final increase in kyphosis. Transpedicular spongiosaplasty is meant to strengthen the broken vertebral body (Daniaux 1991). However, in our study we found no effect of the spondyloplasty. One explanation may be the amount of correction of the W-angle in this series, which seems to be less than that reported in some studies (Aebi 1987, Dick 1987, Esses 1991, Lindsey 1991). The most remarkable finding in our series was the difference between the evolution of the K- and W-angles. The W-angles were stable during the follow-up, except in 3 cases, 2 of whom had a hormonal predisposition to osteoporosis. The PCH was also stable, except in 2 of the cases with increasing W-angles. If we consider the W-angle and the PCH as parameters of the stability of bony deformation, we can conclude that the vertebral body remained remarkably stable in all except one of the patients with a presumably healthy bone structure, and consequently additional transpedicular spondyloplasty did not



provide any significant support. The isolated increase in the K-angle was associated with failure or migration of the implant. The only plausible explanation for an increasing K-angle without an associated increase in the W-angle is collapse of the disc space. Lindsey and Dick observed the same phenomena and suggested that an additional posterolateral fusion could prevent this recurrence of kyphosis. In our series, posterior fusion was performed in most of the cases but it failed to prevent an increase in the K-angles. This is in accordance with the findings reported by a long-term follow-up study of long Harrington rods and a short fusion technique (Akbarnia 1994). The fate of a disc after a burst fracture is not known. Different patterns of healing or degeneration may be crucial for the success of posterior stabilization techniques. In case of a rapid disc collapse, a short-segment posterior instrumentation may be disproportionately loaded and therefore fail.



**CHANGES IN THE DISC SPACE AFTER  
THORACOLUMBAR SPINE FRACTURES**



**CHAPTER 7**

## 7.1 INTRODUCTION

Narrowing of the disc space has commonly been observed after fractures of the thoracolumbar spine and has been associated with progressive kyphosis and pain in conservatively treated patients, or with recurrent kyphosis after posterior reduction and fixation techniques (Malcolm 1981, Denis 1983/b, Lindsey 1991, Steindl 1992, Akbarnia 1994, Sjöström 1995, Speth 1995). It is unclear whether this narrowing is a result of biochemical changes, such as are seen in the degenerative disc disease, or represent an adaptation to changes in the morphology of the disc space as a result of the fracture of the bony endplate. The intervertebral disc is an important element in the height of the motion segment and therefore has an influence on the mechanical properties of the thoracolumbar spine. Different patterns of injury and healing of the discs may be crucial in determining long-term stability (Lin 1993) and may be responsible for complications, which may arise after conservative treatment or posterior reduction and stabilization. This may also explain the remarkable differences in the long-term results of regimes of conservative treatment reported in the literature (Steindl 1992, Denis 1984, Willen 1985, Weinstein 1988, Mumford 1993/a, Cantor 1993). Recurrent kyphosis after posterior fixation has also been used as an argument for employing anterior fixation techniques (Gertzbein 1988, Kaneda 1984, Kostuik 1988). The patterns of degeneration and healing of discs adjacent to fractured vertebra are largely unknown. Our aim was to define the changes in the intervertebral disc space around fractured vertebrae.

## 7.2 MATERIALS AND METHODS

Patients with a history of fracture of thoracolumbar spine attending regular follow-up in our outpatient department between 1994 and 1997 were asked to participate in the study. We excluded those with psychotic conditions. When seen each had standing AP and lateral radiographs. A total of 63 patients (33 men and 30 women) with a mean age of 36 years (17-60) was studied. All had more than 2 years follow up (24-51 months). Of these, 26 had been treated conservatively and 37 by operation. Conservative treatment consisted of immobilization in a cast for 12 twelve weeks. In patients in whom the fractures were classified as unstable, the first six weeks were spent







recumbent. MRI was carried out in this group at a minimum of 18 months after injury. Those undergoing operation had posterior reduction and stabilization with an AO/ASIF internal fixator and a posterior fusion using autologous iliac bone. The fixators were removed between 12 and 18 months later. MRI was carried out at a minimum of six months after this and 24 months after the injury. It was performed according to the standard discopathy protocol of our radiology department (T1: TR: 525 TE: 22; T2: TR: 200 TE: 30; T2: TR: 3362 TE: 150).

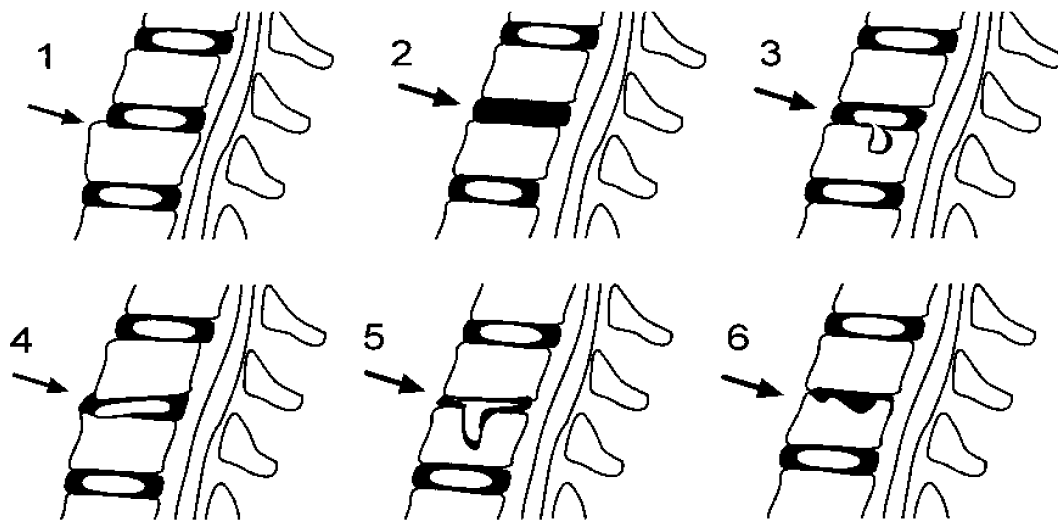
The fractures were classified according to the AO system on the basis of initial radiographs and CT (Magerl 1994). For the changes in the sagittal contour of the spine we used the local angle of kyphosis, which was defined as the angle between the inferior endplate of the superior uninvolved vertebra and the superior endplate of the inferior uninvolved vertebra, and the wedge angle, which is the angle between the superior and inferior endplates of the fractured on lateral radiographs. These measurements were made on the radiograph taken immediately after injury and on the first standing and the last standing films taken at review. In the conservatively treated group, the progression of local kyphosis and the wedge angle were defined as the difference between the first and last standing radiographs. In the operatively treated group the recurrent kyphosis and progression of the wedge angle were defined as the difference in these angles between the first post operative standing radiographs and those taken after the removal of the internal fixation.

Statistical analysis was performed with SPSS/PC+, version 5.0.1. The non-parametric Mann-Whitman U-test was used to compare two groups with the extension to Kruskal-Wallis test with more than two groups. Pearson's correlation test is used for the relationship between different parameters and multiple regression analysis for the effect of different parameters on independent variables. Cohen's Kappa test was used to determine inter- and intra-observer variability.

#### 7.2.1 DEVELOPMENT OF A CLASSIFICATION OF DISC CHANGES

MR scans of the first 35 patients with a total of 38 fractures were evaluated by two different observers using a scheme derived from the system described by Battié et al (1995). This uses a combina-





**Figure 7.1:**  
A diagram of the disc  
types on mid-sagittal  
sections.

tion of morphological and biochemical changes in the anterior, middle and posterior thirds of the disc space. We assessed each of these three sections grading three aspects on a scale of 0 to 3 in comparison with the adjacent discs not involved in the fracture. These were:

**Desiccation:** A change in the signal intensity on T2 images.

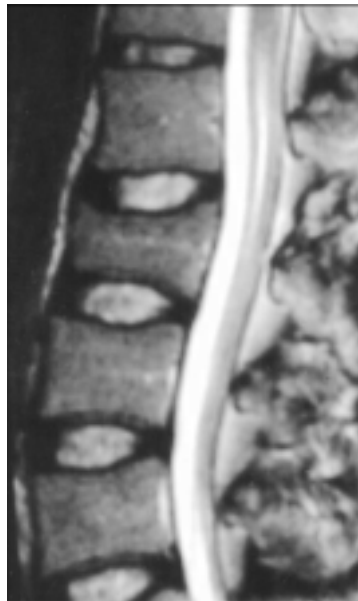
**Bulging or herniation:** This was evaluated according to Battié et al, and we also recorded herniation of the nucleus pulposus into the endplate. T1 and TSE images were used for this analysis.

**Decrease of the disc space:** Graded on T1 and TSE images.

Six different patterns were recognized (Fig. 7.1).

- **Type 1:** Normal or near normal disc. There was no significant loss of height or signal or herniation in any of the three segments (Fig. 7.2).
- **Type 2:** A black disc, which was morphologically similar to type 1 with diffuse loss of signal on T2 images (Fig. 7.3).
- **Type 3:** Schmorl-type change with no significant loss of height or signal. There was a small herniation of the nucleus pulposus into the endplate (Fig. 7.3).
- **Type 4:** Anterior collapse. There was disproportional loss of height in the anterior third but the middle and posterior sec-





**Figure 7.2:**  
*An example of a type 1  
disc (cranial disc).*



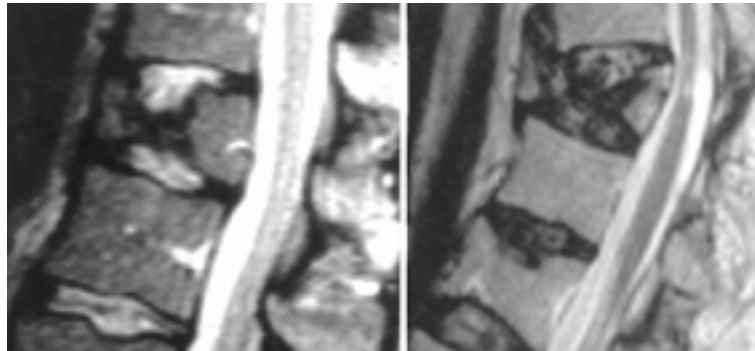
**Figure 7.3:**  
*Examples of type 3  
(cranial disc) and type  
2 (caudal disc) discs.*



**Figure 7.4:**  
An example of a type 4  
disc (cranial disc).



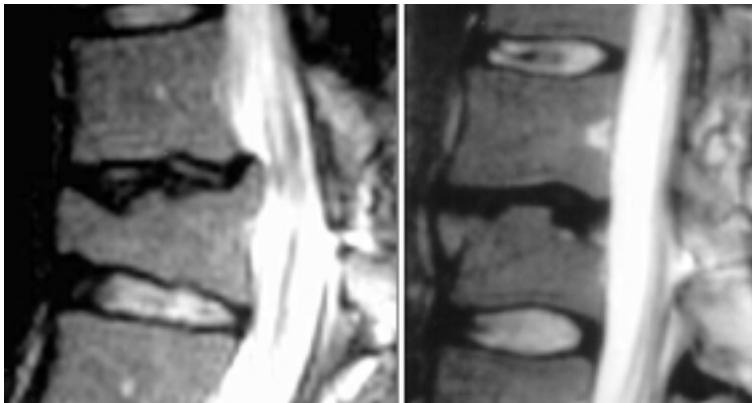
**Figure 7.5:**  
Two examples of type  
5 disc (cranial disc)



tions remained unchanged. Anterior bulging of the disc or herniation of the nucleus pulposus into the endplate in the anterior third. There was no change in the signal intensity of the nucleus pulposus (Fig. 7.4).

- **Type 5: Central herniation.** There was a massive herniation of the nucleus pulposus into the central endplate. As a result of this herniation loss of height in the anterior and posterior sections resulted in almost complete bony contact between the adjacent endplates. The nucleus pulposus in this type has a normal signal intensity (Fig. 7.5).





**Figure 7.6:**  
Two examples of a  
type 6 disc (cranial  
disc)

→ **Type 6:** Degenerated disc. There was loss of disc height and signal intensity on all three sections (Fig. 7.6).

We then used this classification later to evaluate the entire group of 63 patients with 75 fractures and 137 associated discs. The radiologist (LMPR) and the orthopedic surgeon (FCO) categorized the MR images and decided separately on the type of each disc. The orthopedic surgeon reassessed the MR images after a minimum of three months.

### 7.3 RESULTS

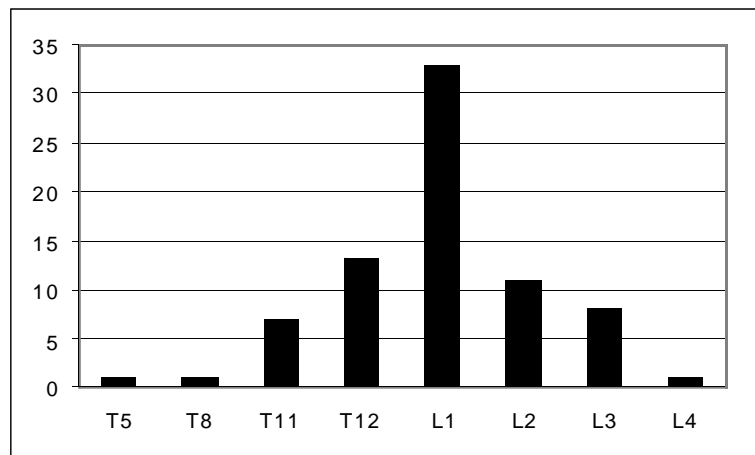
The inter- and intraobserver variabilities of the classification system of the disc types were good (kappa 0.77, SE 0.056, 95% CI 0.66 to 0.88 and kappa 0.79, SE 0.055, 95% CI 0.68-0.9 respectively).

A total of 75 fractures was observed in 63 patients with four having three and four two (Fig. 7.7). The 137 discs adjacent to fractured vertebrae were studied. Fracture types according to the AO classification are shown in Fig. 7.8. The distribution of the disc types is shown in Fig 7.9.

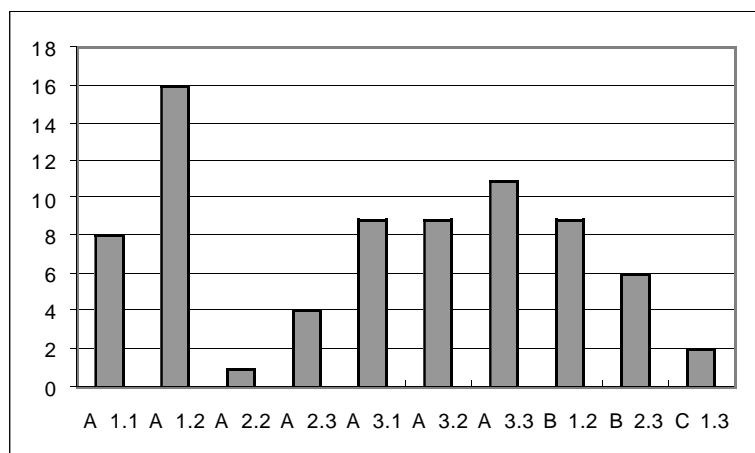
Progression of kyphosis of more than 10° was seen in seven of the 26 patients treated conservatively. There was a corresponding increase of 10° in the wedge angle in only one of them. Four of these patients had a type-4 disc, one a type-5 disc and two a type-6 disc adjacent to the fractured vertebra. None of the patients with type-1, type-2 or



**Figure 7.7:**  
*Histogram showing  
the distribution of  
fracture levels.*

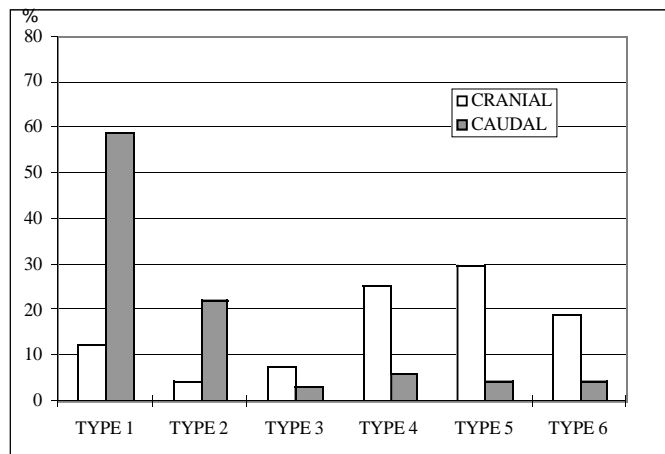


**Figure 7.8:**  
*Histogram showing  
the distribution of  
fracture types  
according to the AO  
classification.*

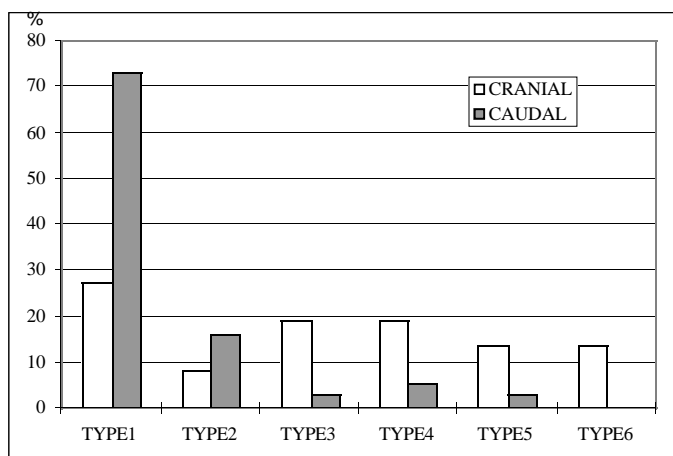


type-3 discs had more than 10° of kyphosis progression. The mean progression of the angle of kyphosis in this group was  $1.6 \pm 2.0^\circ$ . In the group with type-4, type-5 or type-6 discs this mean was  $8 \pm 6^\circ$ . The distribution of disc types in the conservative group is shown in Fig. 7.10





**Figure 7.9:**  
Histogram showing the percentile distribution of disc types in the entire group. Cranial and caudal denote the discs cranial or caudal to the fractured vertebral body.

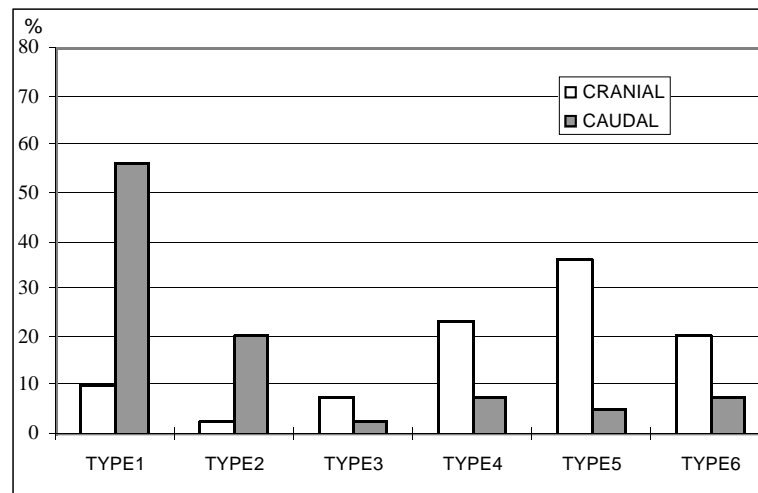


**Figure 7.10:**  
Histogram showing the percentile distribution of disc types in the group treated conservatively.

In the group treated by operation, 25 of the 37 patients had a recurrence of kyphosis of more than  $10^\circ$ . One of these patients had an increase of the wedge angle of more than  $10^\circ$ . The mean recurrence of kyphosis for the group with type-1, type-2 or type-3 discs was  $13 \pm 6^\circ$  and for the group with type-4, type-5 or type-6 discs  $12 \pm 4.3^\circ$ . None



**Figure 7.11:**  
Histogram showing  
the percentile  
distribution of disc  
types in those treated  
by operation.



of the patients treated by operation had a final angle of kyphosis greater than that measured on the initial radiographs after injury. Statistical analysis showed no clear relationship between the degree of recurrence of kyphosis and disc type. The distribution of disc types in the operated group is shown in Fig. 7.11.

The types of fracture and the corresponding disc types observed are summarized in Table 7.1. The caudal disc with type 6 in one of the A 1.1 fracture was cranial to a second fracture. Two of the patients with an A 1.2 fracture had a type-6 disc. Both of these patients had been conservatively treated and showed more than 10° progression of kyphosis. In the A 3 fractures, types 4 and 5 predominated in the discs cranial to the fractured endplate. Only five of the 29 cranial discs involved in such a fracture were of type 6. Two of the caudal discs of type A 3.2 fractures had also a type-6 disc. Other than what would be expected from fracture mechanism, not all type B fractures showed extensive disc degeneration.

#### 7.4 DISCUSSION

Our main finding was the lack of a consistent change in signal in the disc space after fractures of the endplate. This was also noted by Rudig et al (1997). Only two of the types defined in our study







TYPE #	N		TYPE 1	TYPE 2	TYPE 3	TYPE 4	TYPE 5	TYPE 6
A 1.1	8	CRANIAL	3	1	3	1		
		CAUDAL	7					1
A 1.2	16	CRANIAL	6	1	5	2		2
		CAUDAL	15			1		
A 2.2	1	CRANIAL				1		
		CAUDAL		1				
A 2.3	4	CRANIAL	1			1	2	
		CAUDAL	2			1	1	
A 3.1	9	CRANIAL			1	3	3	2
		CAUDAL	8	1				
A 3.2	9	CRANIAL			1	1	6	1
		CAUDAL	2	4	1			2
A 3.3	11	CRANIAL	1			3	5	2
		CAUDAL	3	5		2	1	
B 1.2	9	CRANIAL	1	2		2	1	3
		CAUDAL	6	2		1		
B 2.3	6	CRANIAL	1			2	1	2
		CAUDAL	4	1	1			
C 1.3	2	CRANIAL					1	1
		CAUDAL	1				1	

**Table 7.1:**

*Fracture types compared with the observed disc types.*

showed major changes in signal intensity (Types 2 and 6). Roaf (1960) observed that under compression the discs are always stronger than the end plate and that compression forces create a fracture of the endplate before damage to the intervertebral disc. Holdsworth (1963, 1970), in his concept of a two-column spine, maintained that after compression fractures the disc remains intact, which is why he called 'burst fractures' stable injuries. Our study seems to confirm these earlier observations. In most of our cases the signal intensity of the discs seemed to be preserved and most changes were related to morphological alterations in the disc space. This does not seem to be a result of posterior fixation, because the difference in the distribution of disc types between the conservative and operative groups is largely due to the difference in the incidence of different fracture types in the two groups (Figs 7.10 and 7.11).



Our identification of different types of disc suggests common traumatic patterns, which result in different types of morphology in the disc space relatively independent of the fracture classification. The effects of these common patterns seem to vary according to treatment. In posteriorly stabilized fractures the different disc types did not result in a discernible variation in radiological appearances, whereas there was a relationship in the conservatively treated group. Posterior stabilization may have neutralized the effects of different patterns of trauma.

Recurrent kyphosis after posterior reduction was commonly seen and appears to be a result of the creeping of the nucleus pulposus back into the depressed central area. Posterior reduction probably reduces only the periphery of the endplate with strong annular attachments while the central area remains depressed. After removal of the internal fixation, the disc settles in this depressed area causing narrowing of the disc space and amplifying the residual kyphosis. The wedge angle on the radiograph can be deceptive when used to measure the degree of reduction of the segment. Once the fracture of the endplate has healed resettlement does not cause progression of the kyphosis to a degree greater than the original deformity. Transpedicular spongionoplasty may restore depression of the endplate and prevent the creeping of the disc (Daniaux 1991). Most of the central depressions occur in the posterior half of the endplate and are probably inaccessible through the pedicels, which may explain the varying success of this technique reported in the literature (Daniaux 1991, Crawford 1994, Speth 1995). Transpedicular discectomy has also been proposed to prevent the recurrence of kyphosis (Eysel 1994), but our results show that discs are in most cases intact and thus probably provide stability to the damaged segment. Any attempt to remove the disc may further destabilize the injured segment and cause failure of fixation. In our view, changes in the disc space after posterior fixation should not be seen as a form of chronic instability but as a redistribution of the disc tissue in the changed morphology of the disc space without endangering the mechanical stability of the involved motion segment.

In the conservatively treated group, changes in the disc have more influence on the progression of kyphosis. No attempt had been made to reduce the fractures. Injuries leading to disc types 1, 2 or 3 did not





cause any progression of kyphosis, while those leading to types 4, 5 or 6 were associated with progression in some cases. Our conservatively treated group was too small to reach any conclusions about the effects of disc types 4, 5 or 6 separately, since more severe cases were treated by operation. Our scheme of classification can be useful for further study. If progression of kyphosis can be predicted, the decision as to whether to treat conservatively or by operation can be rationalized. We should not forget, however, that fractures of the thoracolumbar spine are complex injuries of an intricate structure and the changes in the disc space are only one of many possible parameters involved. The final clinical and radiological results depend on many factors such as the morphology of the resulting deformity of the endplate, the amount of comminution, the degree of osteoporosis, or involvement of ligament structures. Changes in the disc space may only amplify the effects of some of these factors.

It can be argued that eventually all discs adjacent to fractures will degenerate, but the degree of kyphosis observed after longer follow-up period does not seem to be greater than that at two years (Akbarnia 1994, Speth 1995).

Our study also questions the nature of 'degenerative disc disease'. This is accompanied by desiccation of the nucleus pulposus, which is related to biochemical changes in the entire disc space. Animal experiments have shown rapid desiccation and biochemical changes in the nucleus pulposus after a lesion of the annulus fibrosus (Osti 1990). Traumatic injuries to the disc have been regularly proposed as a cause of the disc degeneration. In our study, lack of consistent signal changes after a major traumatic event to the motion segment does not support the idea of a traumatic origin to degenerative disc disease. Fracture of the endplate alone was not sufficient to cause disc degeneration in the period observed in this study.





**PROGNOSTIC SIGNIFICANCE OF MRI  
FINDINGS OF THE FRACTURES OF THE  
THORACOLUMBAR SPINE**  
A Prospective Study of 53 Patients



**CHAPTER 8**

## 8.1 INTRODUCTION

The proper treatment of fractures of the thoracolumbar spine has been debated for some time. Numerous studies have been published with a wide variety of clinical and radiological outcomes, which often contradict each other. Proponents of non-operative management claim that almost all types of injury, as long as there is no neurologic involvement, can be successfully treated with conservative measures alone (Shen 1999). However, long-term complications after conservative treatment such as persistent pain and progressive deformity are well known and recognized (D'Ariano 1995). There is no unanimity about the "conservative" treatment regimes. These differ from an almost "benign neglect" policy to strict recumbence for periods varying between 4 to 12 weeks. The selection criteria for inclusion in conservative treatment regimes are also highly variable and in most of the studies subject to variations during the study period. The mechanisms of failure of these treatment regimes are poorly understood.

The operative treatment options have their own problems. The most commonly used posterior reduction techniques have in some series high rates of hardware failure (McCormack 1994, McLain 1993, Speth 1995). Another problem is the well-known recurrence of the kyphotic deformity after hardware removal (Speth 1995, Oner 1998). These problems have led some of the authors to abandon the posterior techniques in favor of anterior reconstruction. However, this involves extensive dissections with higher morbidity and probably higher complication and revision rates (Knop 1998). Another problem with anterior techniques is that usually the injured segment has to be removed partially or completely and replaced by some kind of a prosthetic device, which is undesirable for various reasons in the younger patients.

Much of this controversy is due to a lack of reliable prognostic parameters. With the present means of distinction, it is not possible to predict failure of conservative treatment or posterior reduction techniques. "Failure" of the treatment is also poorly defined and varies from minor residual deformities without a well-defined clinical relevance to incapacitating pain or progressive neurologic deficit leading to a secondary operative procedure. This confusion results in the pre-





dominance of “cultural” preferences of the clinic treating the patient. There is insufficient data to make a sound, evidence-based decision on different treatment options for the individual patient. Most of the series in the literature are retrospective studies with insufficiently described diagnostic modalities and follow-up procedures. The only large-scale prospective multi-center survey was conducted by the Scoliosis Research Society between 1986-1991 (Gertzbein 1992). Although providing valuable data, this survey had some shortcomings. Because of the multi-center character of the survey there were differences in the indications for operative treatment, imaging modalities were not standardized, classification of the injuries were left to different participants, and a very low (40%) percentage of patients had an adequate follow up.

Our aim in this prospective study was to investigate the clinical and radiological factors, which would help predict failure of conservative treatment or posterior fixation techniques. We created a cohort of consecutive patients with adequately described lesions who were treated according to an inclusion and treatment protocol, unchanged during the study period, and who were followed up according to a protocol considering radiological and clinical parameters. In such a study it is necessary to describe the injury patterns to all structures involved in order to be able to detect possible prognostic factors. Earlier clinical and experimental studies established the MRI as a most sensitive imaging modality capable of depicting injuries to ligaments, discs, endplates and vertebral bodies accurately (Saifuddin 1996, Oner 1999/a, Flanders 1999, Oner 1999/b). A recently described scheme allows a detailed categorization of all structures involved in the acute and long-term stability of the fractured spine (Oner 1999/b). We used this scheme to investigate the prognostic significance of different injury patterns as seen on the injury MRI.

## 8.2 MATERIALS AND METHODS

This prospective study started in September 1994. All patients with a traumatic fracture of the thoracolumbar spine necessitating active treatment (operative or non-operative) were included. All pathologic fractures including osteoporotic fractures caused by minimal trauma were excluded. Patients were informed that they are



included in a prospective study, which requires long follow up and control MR scans. Standard AP and lateral radiograms, CT scans, and T1 weighted (TR 578; TE 25) and T2 weighted (TR 2000; TE 100) MR images were obtained during the first week after admission. MR imaging was performed in the sagittal plane and in case of neurologic deficit additional transverse plane images were obtained. MR imaging was not possible in case of polytrauma necessitating long periods of assisted ventilation or emergency intervention. Therefore the MR imaging for ten patients, who would be suitable for inclusion in the study, could not be performed during this period. These patients were excluded. Further in six other patients MRI's could not be obtained because of unrest due to unresolved psychotic conditions. Decision about treatment options was taken by one of the two orthopedic spine surgeons in all cases. For this decision, the surgeons used the classification by Magerl et al (1994) as a guideline using all available imaging including the MRI's. All patients were treated according to the following protocol:

- Patients with stable fractures (Types A 1, A 2 and A 3.1 with less than 15 degrees of kyphosis and without neurologic involvement) were treated conservatively.
- All patients with neurologic involvement were treated operatively.
- Patients with unstable fractures without neurologic involvement were asked to make a choice between operative and conservative treatment after they were informed about the advantages and disadvantages of both treatment options.

Conservative treatment consisted of immediate ambulation with a Neofract® plastic orthosis during 6 weeks in case of a stable fracture. Patients with fractures that were considered unstable were immobilized with the same kind of cast and remained in bed for 4-6 weeks. The cast was worn until 12 weeks after the injury.

For the operatively treated group, the treatment of choice was posterior short segment pedicle fixation with AO internal fixator, or Isola system in case of necessity for long traject fixation. Only in case of expected difficulties with short segment fixation such as abnormal pedicular structure was primary anterior surgery performed with a double rod Kaneda construct. For patients with partial neurological







- P1: No pain
- P2: Occasional minimal pain with no need for medication
- P3: Moderate pain with occasional medication but no interruption of work or significant change in activities of daily living
- P4: Moderate to severe pain with frequent medication and occasional absence from work or significant change in activities of daily living
- P5: Constant or severe incapacitating pain, chronic medication.

- W1: Returned to previous employment (heavy labor)
- W2: Able to return to previous employment (sedentary) or return to heavy labor with restrictions or modifications
- W3: Unable to return to previous employment but working full time at a new job
- W4: Unable to return to previous employment - working part-time or frequently absent from work because of pain
- W5: No work - completely disabled.

**Table 8.1:**

*Pain and work scores according to Denis (1984).*

involvement, posterolateral decompression was performed through a partial laminectomy and direct reduction of the protruding bone segment. Fusion of the fractured vertebra with the upper and lower uninjured vertebrae with autologous iliac bone was performed in each case. No transpedicular spongionoplasty or transpedicular discectomy was performed. Patients were verticalized as soon as the general condition allowed. A Neofract® cast was worn for 12 weeks after the operation. Hardware was removed after 12 - 18 months.

Standing (or sitting in case of serious unresolved neurologic involvement) AP and lateral radiographs were obtained at the initial verticalization and thereafter at six weeks, 12 weeks, 6 months, one year and later each year. Two years after the initial trauma, follow-up MRI's were obtained. At that time pain and work scores were obtained by residents, not involved in the initial treatment of the patients, during routine outpatient visits using neutral questions as part of the patient history. Pain and work status was categorized according to the scales proposed by Denis et al (Denis 1983/b) (Table 8.1).

Kyphosis and wedge angles were measured on the trauma (initial), the first standing (treatment) and the last standing (follow up) lateral radiographs. The local kyphosis angle was measured between the lower end plate of the cranial uninvolved vertebra and the upper end



plate of the caudal uninvolved vertebra. The wedge angle was measured between the upper and lower endplates of the fractured vertebra. For the operatively treated group the load sharing classification was calculated as described by McCormak et al (1994) using the CT images.

For the injury MRI's the scheme described by Oner et al (1999/b) (section 5.2) was used to categorize the states of the different structures involved. This scheme categorizes the structures that may have consequences for the initial and long-term mechanical stability of the spine and for which there is sufficient experimental and clinical evidence for reliable imaging with MRI. The various categories are called "states" because some imply no injury to the structure involved. These states were categorized on a scale of 1 to 4 in which state 1 represents no or minor injury with no mechanical consequences and higher grades implying higher probability of mechanical impairment. For the changes in the disc space on the follow up MRI's the classification of Oner et al (1998) (Section 7.2.1) was used.

**Statistics:** Statistics were performed on a PC with the SPSS, Statexact, and MlwiN packages. Comparison of conservatively treated and operatively treated groups with respect to pain and work score has been done using the chi-squared test with calculation of exact p-values. In the conservatively treated group of 24 patients there were eight patients with more than one fracture. Choosing the dependent variables of interest as occurrence of increase of kyphosis angle  $\geq 5$  degrees and occurrence of pain score  $\geq 3$ , we have analyzed the conservatively treated group by means of conditional logistic regression (or equivalently multilevel analysis). For the operatively treated group of 29 patients there were only three patients with two fractures. Therefore the data for this group was analyzed by ordinary logistic regression, neglecting the dependence of the data of these three patients. For both groups the explanatory variables were sex, age, parameters of injury MRI, kyphosis angles, and wedge angles. For patients with more than one fracture the kyphosis and wedge angles were summed and for the MRI parameters the highest score was used for the calculations. Pain scores were categorized into two groups: P1 and P2 as no or mild pain; and P3 or higher as significant pain.





### 8.3 RESULTS

Out of the 60 patients who were included in the study in the period September 1994 - December 1996, three (two in conservative and one in operative group) were lost to follow up. One patient in the operative group returned to his work as a sailor and could not find time to get his hardware removed. One patient in the operative group undertook a second suicide attempt, which resulted in multiple fractures in segments adjacent to the initial fracture. One patient in the conservative group was unable to finish the follow up MRI because of claustrophobia. One patient in the conservative group refused further follow up after one year. These patients were excluded from the study. This left 53 patients, who completed the study with minimal 24 months of follow up and all radiological examinations according to the study protocol.

These 53 patients had 71 fractures. 30 of the patients were men. 42 patients had single level fractures, six patients two fractures, three patients three fractures and two patients four fractures. The average follow up was 32.2 (24-52) months. 24 patients with 39 fractures were treated conservatively and 29 patients with 32 fractures were treated operatively. 28 patients with 31 fractures were operated with posterior pedicle screw constructs and one patient with a single fracture was operated on anteriorly with a Kaneda device. The two groups of conservatively and operatively treated patients were comparable for age and sex distribution.

#### 8.3.1 CONSERVATIVE GROUP

The general patient data for this group are shown in table 8.2. 13 of the patients were men and 11 women. The average age was 37 (14-62) years. The average increase in the kyphosis angle was 2.8 degrees (-4 to 18). Ten fractures showed 5 degrees or more increase in the kyphosis angle. The average change in the wedge angle was - 0.2 (-7 to 8) degrees. Only one fracture showed more than 5 degrees increase in the wedge angle. 13 patients with 23 fractures had no or occasional pain (P1 and P2). 11 patients with 16 fractures had moderate to severe pain (P3 or higher), necessitating regular use of analgesics and/or interfering with their work and ADL. When we analyzed these two groups separately we found that the first group (with P1 or



NO	AGE	SEX	LEVEL	TYPE	KAI	KAT	KAF	DK	WAI	WAT	WAF	DW	PAIN
1	27	M	L4	A2.2	-3	0	0	0	8	8	8	0	2
2	29	F	T12	A3.2	17	17	15	-2	17	15	15	0	1
3	47	F	L1	A3.1	12	10	14	4	18	16	16	0	4
4	62	M	T12	A3.3	8	5	17	12	12	10	14	4	3
5	57	M	T10	A1.1	5	5	5	0	5	5	5	0	2
5	57	M	T12	A1.1	5	5	5	0	5	5	5	0	2
5	57	M	T11	A2.2	10	10	20	10	20	20	22	2	2
6	48	M	T12	A3.2	10	10	16	6	14	12	10	-2	3
7	29	M	T12	B1.2	24	25	24	-1	14	12	12	0	1
7	29	M	L2	A1.1	5	5	5	0	5	5	5	0	1
7	29	M	L3	A1.1	5	5	5	0	5	5	5	0	1
7	29	M	L4	A1.1	0	0	0	0	0	0	0	0	1
8	54	F	T12	A3.1	4	4	15	11	7	8	10	2	4
9	49	M	L1	A1.2	10	8	8	0	13	10	10	0	3
10	27	F	L1	A3.1	8	7	7	0	14	12	12	0	3
11	25	M	T12	B1.2	10	10	10	0	12	12	12	0	2
12	21	M	T8	A3.1	23	23	25	2	21	20	20	0	3
12	21	M	T11	A1.1	10	10	10	0	6	6	6	0	3
12	21	M	L3	A1.2	-10	-10	8	18	8	8	1	-7	3
13	14	M	L1	A3.3	10	8	14	6	18	18	18	0	1
14	46	M	L1	A3.2	0	12	14	2	17	19	12	-7	2
15	42	M	T11	A1.2	12	12	18	6	12	12	20	8	2
15	42	M	T9	C1.2	8	8	8	0	4	4	4	0	2
15	42	M	T8	A1.1	10	10	10	0	5	5	5	0	2
15	42	M	T7	A1.1	10	10	10	0	5	5	5	0	2
16	27	M	L3	A1.1	0	0	0	0	0	0	0	0	3
16	27	M	L1	A1.2	4	4	18	14	3	9	4	-5	3
17	57	F	L1	A3.3	16	20	23	3	18	18	18	0	4
18	28	F	L1	A3.1	10	10	10	0	5	5	5	0	3
18	28	F	L2	A1.2	0	0	0	0	5	5	5	0	3
18	28	F	L3	A1.2	0	0	5	5	5	5	5	0	3
19	46	F	L1	A2.3	0	8	20	12	8	10	10	0	3
20	24	F	T12	A1.1	8	8	8	0	10	10	10	0	1
20	24	F	L1	B2.3	8	8	8	0	10	10	10	0	1
21	15	F	L1	B1.2	5	5	8	3	20	8	8	0	1
22	50	F	T12	A3.3	10	12	18	6	18	18	18	0	1
23	25	M	T5	A1.1	14	14	14	0	8	8	8	0	1
23	25	M	L1	A1.2	8	8	10	2	17	14	12	-2	1
24	40	M	L2	A1.2	8	8	10	2	10	10	10	0	4

**Table 8.2:**

*General data of the conservatively treated patients. Patients with multiple fractures are shown under the same patient number. KAI: Initial kyphosis angle; KAT: Kyphosis angle on the first standing radiogram; KAF: Kyphosis angle on the final standing radiogram; DK: Difference between KAT and KAF; WAI: Initial wedge angle; WAT: Wedge angle on the first standing radiogram; WAF: Wedge angle on the final standing radiogram; DW: Difference between WAT and WAF.*





	Group 1	Group 2
Age	32.54 (14 – 57)	42.6 (21 – 62)
Difference in KA	0.9 ( -4 – 6)	5.5 ( 0 – 18)
Final KA	10.4 (0-24)	12.3 (0-25)
Final WA	9.96 (0-26)	9.13 (0-20)

**Table 8.3:**

*Some of the characteristics of the conservatively treated patients with pain scores of 1 and 2 (group 1) and pain scores of 3 or more (group 2).*

P2) had an average increase in the kyphosis angle of 0.9 (-4 to 6) degrees and the second group (with P3 or higher) 5.5 (0 to 18) degrees. Some of the characteristics of these two groups are shown in table 8.3. Only three patients had more than 5 degrees of increase in the kyphosis angle without significant pain. Four patients with increase in kyphosis angle of less than 5 degrees had pain scores of 3 or more. If we consider more than occasional pain and/or progression of kyphosis of more than 5 degrees as unsatisfactory outcome of treatment, 14 out of 24 patients were failures. None of the four patients with a type B fracture had a more than 5 degrees kyphosis or more than occasional pain. The only patient with a type C fracture had 6 degrees increase in the kyphosis angle, no increase in scoliosis and no pain.

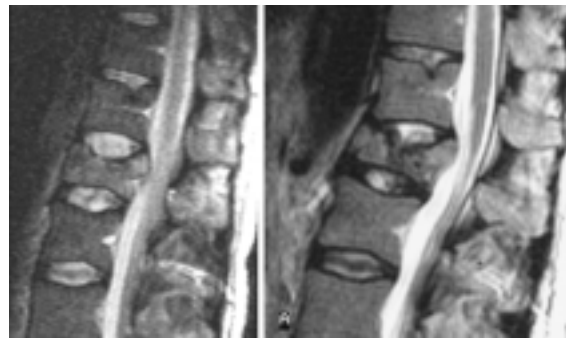
The most common mechanism of kyphosis increase was through a progressive settlement of the disc into the fractured endplate and vertebral body (Figures 8.1, 8.2, 8.3). Although the failure mechanism was in most cases apparent in retrospective analysis, some fractures that were practically identical on the injury MRI resulted in different types on follow-up MRI (Figure 8.4).

The following conclusions were reached by statistical analysis:

- No significant relation was found between the number of fractures and the pain score.
- Significant relation was found between the increase in kyphosis angle and age (age older or younger than 30 years, two-tailed  $p=0.036$ , older patients having more often increase).
- Chi-square analysis showed possible relations between pain score and the trauma MRI parameters (two-tailed  $p$ -values):



**Figure 8.1:**  
*Settlement of the disc  
into the endplate in a  
conservatively treated  
patient. a: trauma; b:*  
*follow-up.*

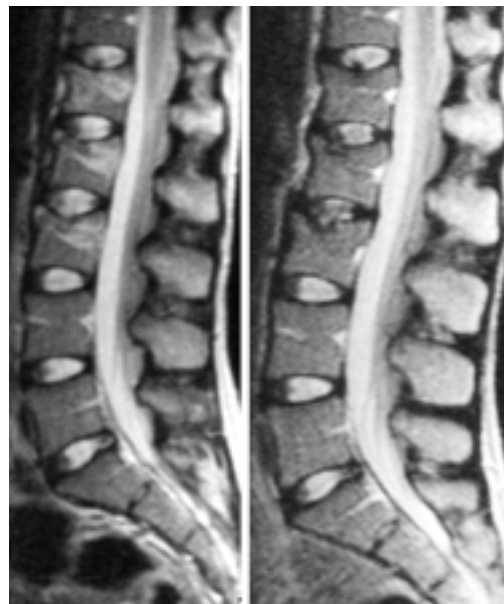


**Figure 8.2:**  
*Progression of  
kyphosis through  
settlement of the disc  
into the split endplate  
in a conservatively  
treated patient (#19).  
a: injury MRI; b:*  
*follow-up.*





**Figure 8.3:**  
*Progression of  
kyphosis through  
further splitting of the  
endplate by the disc in  
a conservatively  
treated patient (#22).  
a: injury MRI; b:  
follow-up.*



**Figure 8.4:**  
*In this patient (#18)  
with three consecutive  
fractures the injury  
MRI (a) shows almost  
identical fractures,  
although the L1  
fracture is classified  
as A 3.1 because of  
minimal posterior  
cortex involvement.  
On follow-up (b) only  
the L3 fracture shows  
progression of  
kyphosis through  
settlement of the disc.*



DI CR (p=0.082)

EP CR (p=0.083).

→ Logistic regression analysis showed possible relations in the differences between the patients with pain scores < 3 and those with pain scores ≥ 3 concerning the following parameters (two-tailed p-values):

Age (p=0.086)

Difference in kyphosis angle (DK) (p=0.018)

Difference in wedge angle (DW) (p=0.066)

MRI parameter EP CR (p=0.069)

MRI parameter DI CR (p=0.104).

→ Significant relations were found between the increase in kyphosis angle and the following MRI parameters:

EP CR (p=0.049)

EP CA (p=0.048)

DI CR (p=0.019)

DI CA (p=0.013)

→ Logistic regression analysis was performed to investigate combinations of the MRI categories that would predict increase of the kyphosis angle of more than 5 degrees. Only the combination of the parameters EP CR (cranial endplate) and COR (vertebral body involvement) was found to have significant predictive value (chi-square =10.3966 with 4 degrees of freedom, p=0.034). More than 50% chance of increase in kyphosis angle was found for the combinations of the MRI states:

EP CR 1 - COR 3 (0.51),

EP CR 2 - COR 2 (0.55),

EP CR 2 - COR 3 (0.79).

→ Concerning the disc categorization on the follow-up MRI there was only a significant difference in the distribution of type-1 disc between the group with < 5 degrees of increase in kyphosis angle and the group with ± 5 degrees in kyphosis angle in that the first group had more type-1 discs.

→ With the numbers available no significant relation was found between the classification of the fractures and the pain score or increase in the kyphosis angle.







### 8.3.2 OPERATIVE GROUP

The general patient data of this group are shown in table 8.4. The average age was 36.2 (18-58) years. 17 patients were men and 12 women. The details of the surgical levels, implants and complications are shown in table 8.5. The wound infection of the patient #44 resolved after debridement and antibiotics. The cultures taken during the hardware removal were sterile. The broken screw in patient #53 did not seem to influence the course, as solid fusion was found during hardware removal. The pull out of the distal screws in the patient #42 with paraplegia necessitated hardware removal 4 months after the operation.

The amount of surgical correction of the kyphosis angle and the wedge angle was 12.6 (0 to 26) degrees and 10.4 (4 to 34) degrees respectively. The initial and final kyphosis angles and wedge angles together with the amount of correction and recurrence after hardware removal are shown in table 8.6. Only one patient had a final kyphosis angle higher than 5 degrees with respect to the initial kyphosis angle (patient #49). No patient had a final wedge angle greater than the initial wedge angle. 12 patients had more than 10 degrees of recurrence of kyphosis (defined as the difference between the final kyphosis angle and the kyphosis angle measured on the first standing radiogram after the operation). In only two of these patients there was a corresponding 6 degrees of recurrence of the wedge angle.

Only two of the patients in this group had moderate pain (P3) necessitating regular use of analgesics. One was patient #42 with pull out of screws mentioned before. This patient with complete paraplegia had probably a combination of mechanical and neurogenic pain but refused further analysis or a secondary procedure. The other was patient #38, a 45 year old female with a recurrence of kyphosis of 10 degrees. This patient began complaining of the pain after hardware removal.

The main mechanism of kyphosis recurrence was through creeping of the disc in the central depression of the endplate. It was clearly seen that posterior reduction reduced only the periphery of the endplate with its strong annular attachments while the central area remained depressed. This resulted in a nice correction of the wedge angle on the post-operative radiograms but after hardware removal the disc set-



NO	AGE	SEX	LEVEL	NE	TYPE	KAI	KAT	DCK	KAF	DK	WAI	WAT	DCW	WAF	DW	LS	PAIN
25	24	M	L2	E	A3.2	0	-18	18	-10	8	14	6	8	9	3	6	2
26	32	F	L1	E	A3.1	20	-6	26	2	8	34	0	34	5	5	7	1
27	23	F	T6	E	B2.3	18	7	11	9	2	18	5	13	8	3	7	1
28	32	M	L1	E	B1.2	17	0	17	9	9	20	10	10	10	0	3	2
29	58	M	L3	D	A3.3	0	-10	10	3	13	10	0	10	0	0	8	1
29	58	M	L4	D	B2.3	8	-8	16	0	8	16	14	2	14	0	4	1
30	56	F	L1	E	A3.3	8	0	8	8	8	10	8	2	8	0	7	2
31	47	M	T11	A	B2.3	31	20	11	30	10	40	34	6	40	6	10	2
32	28	F	L1	E	C1.3	16	0	16	10	10	14	0	14	2	2	6	1
33	40	M	T12	C	A3.3	22	4	18	16	12	23	13	10	12	-1	9	1
34	30	M	T12	D	A3.2	5	5	0	5	0	5	5	0	5	0	6	2
34	30	M	L3	D	A3.3	0	-13	13	-5	8	18	5	13	5	0	9	2
35	59	M	T12	A	B1.2	9	0	9	0	0	19	5	14	5	0	5	1
36	52	M	L1	B	A3.1	15	0	15	8	8	16	0	16	7	7	5	1
37	54	M	L3	E	B1.2	-3	-10	7	-10	0	8	0	8	0	0	4	1
38	45	F	L1	E	A3.2	15	5	10	15	10	22	10	8	12	2	4	3
39	20	F	L1	D	B1.2	15	4	11	10	6	15	10	5	10	0	5	1
40	22	F	L1	E	B1.2	15	0	15	0	0	20	0	20	0	0	8	1
41	41	M	L3	C	A3.3	0	-10	10	8	18	15	10	5	10	0	8	2
42	27	M	L1	A	C2.1	10	10	0	10	0	20	10	10	15	5	6	3
43	46	M	L1	E	A3.3	18	0	18	18	18	22	18	4	18	0	5	1
44	54	F	L1	D	A1.1	5	0	5	0	0	8	0	8	0	0	3	1
44	54	F	L2	D	A3.3	18	0	18	6	6	22	5	17	5	0	9	1
45	31	F	L1	E	A3.3	13	0	13	16	16	25	3	22	9	6	8	2
46	47	M	L1	E	A3.1	20	0	20	8	8	20	8	12	10	2	7	1
47	21	M	T11	A	B1.2	15	0	15	5	5	20	5	15	5	0	8	1
48	18	M	L3	D	A3.2	1	-12	12	6	18	20	8	12	5	-3	6	1
49	18	F	L3	E	A3.3	10	10	0	16	6	12	12	0	10	-2	7	1
50	42	M	L2	C	B2.3	15	-5	20	5	10	20	8	12	8	0	9	2
51	30	F	T12	E	A3.1	10	0	10	10	10	23	12	11	12	0	8	1
52	37	M	L1	E	B2.3	13	0	13	10	10	16	12	4	13	1	10	1
53	23	F	L1	E	B2.3	26	8	18	28	20	14	6	8	8	2	9	2

**Table 8.4 :**

*General data of the operatively treated patients. Patients with multiple fractures are shown under the same number. NE: Neurology, Frankel grade; KAI: Initial kyphosis angle; KAT: Kyphosis angle on the first standing radiogram; DCK: Amount of correction of the KA; KAF: Kyphosis angle on the final standing radiogram; DK: Difference between KAT and KAF; WAI: Initial wedge angle; WAT: Wedge angle on the first standing radiogram; DCW: Amount of correction of the WA;WAF: Wedge angle on the final standing radiogram; DW: Difference between WAT and WAF. LS: Value according to the load sharing classification.*



# PROGNOSTIC SIGNIFICANCE OF MRI FINDINGS



NO	INSTR LEVEL	INSTR	COMPLICATION
25	L1-L3	AO	-
26	T12-L2	AO	-
27	T5-T7-T8	ISOLA	-
28	T12-L2	AO	-
29	L2-L3-L4-L5	ISOLA	-
30	T12-L2	AO	-
31	T9-T10-T12-L1	ISOLA	-
32	T12-L2	AO	-
33	T11-L1	AO	-
34	L2-L4	AO	-
35	T11-T12	ISOLA	-
36	T12-L2	AO	-
37	L2-L4	AO	-
38	T12-L2	AO	-
39	T12-L2	AO	-
40	T12-L2	KANEDA	-
41	L2-L4	AO	-
42	T11-T12-L1-L2	ISOLA	Pull out dist screws
43	T12-L2	AO	-
44	T12-L1-L3	AO	Infection
45	T12-L2	AO	-
46	T12-L2	AO	-
47	T9-T10-T12-L1	ISOLA	-
48	L1-L3	AO	-
49	L2-L4	AO	-
50	L1-L3	AO	-
51	T11-L1	AO	-
52	T12-L2	AO	-
53	T12-L2	ISOLA	distal left screw broken

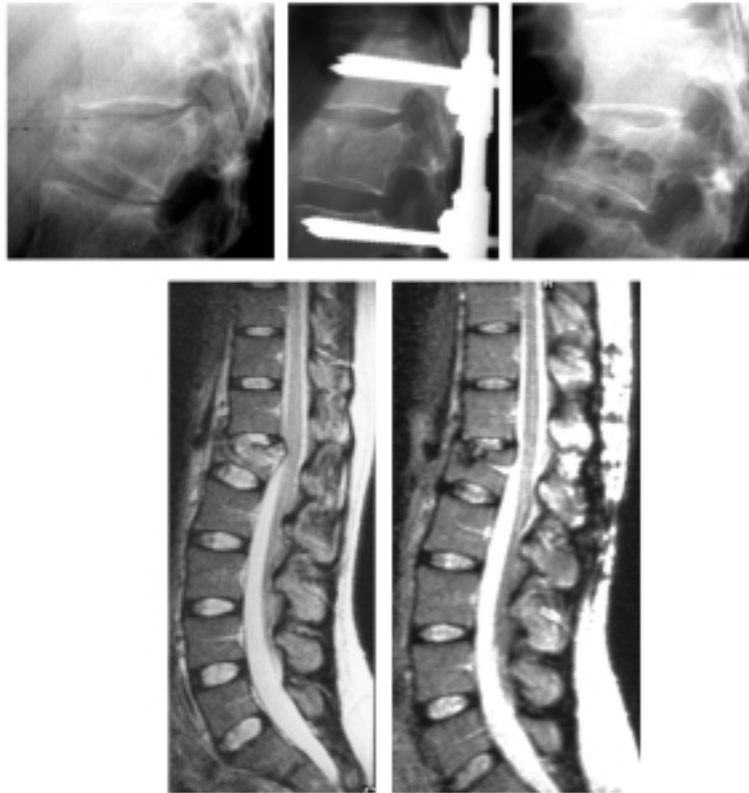
**Table 8.5:**  
*Instrumentation levels, type of implants and complications.*

	Kyphosis Angle	Wedge Angle
INITIAL	12 (-3-31)	18.1 (5-40)
CORRECTION	12.6 (0-26)	10.4 (4-34)
FINAL	7.7 (-10 - 30)	8.75 (0-40)
RECURRENCE	8.3 (0-20)	1.2 (-3 - 7)

**Table 8.6:**  
*Average values with ranges of the initial kyphosis and wedge angles, the amount of surgical correction, final values and the amount of recurrence.*



**Figure 8.5:**  
*The mechanism of  
 kyphosis recurrence  
 after posterior  
 reduction (patient  
 #45): Nice reduction of  
 both the kyphosis and  
 the wedge angles (a  
 and b). Recurrence of  
 kyphosis after  
 hardware removal (c)  
 without an  
 accompanying  
 recurrence in the  
 wedge angle. Injury  
 (d) and follow-up  
 MRI's (e) show that  
 the central impression  
 remained practically  
 unchanged.*



tled in this depressed area causing narrowing of the disc space and amplifying the residual kyphosis. In all cases the central depression of the endplate on follow up MRI's was identical to the depressions seen on injury MRI's, independent of the amount of surgical correction of the kyphosis angle or the wedge angle (Figure 8.5).

Statistical analysis was used to investigate the relation between the recurrence of the kyphosis angle and the clinical and radiological parameters. Significant relation was found with the amount of kyphosis reduction ( $p=0.031$ ). Logistic regression analysis showed that none of the parameters alone or in combination had a significant predictive value with the exception of the injury MRI variable PLC (two-tailed  $p=0.066$ ). Out of the 11 fractures with PLC state 1 (no injury), only





**Figure 8.6:**  
*Adequate  
decompression by a  
patient (#44) with  
partial neurologic  
involvement.*

one had 10 degrees of kyphosis recurrence. Out of the 14 patients with PLC state 2 or 3 (partial involvement) ten had kyphosis recurrence of 10 degrees or more and out of the seven patients with PLC state 4 (complete disruption) two had more than 10 degrees of kyphosis recurrence. No significant correlation was found between the recurrence of kyphosis and pain, the final kyphosis angle and pain or between the final disc types and pain. Load-sharing classification was not predictive of the recurrence of kyphosis.

### 8.3.3 NEUROLOGIC INVOLVEMENT:

Four patients had a complete paraplegia (Frankel A) and 12 patients had incomplete neurologic involvement. Only one of the patients with complete paraplegia showed substantial improvement of his neurologic status (patient # 31). At the last follow up 36 months after trauma he could walk independently and was classified as Frankel D. The improvement of the patients with incomplete paraplegia depended, as expected, on the level of injury. Cauda equina lesions showed in all cases improvement while conus injuries did not. Judging from the comparison of follow up MRI's with injury MRI's, posterolateral decompression seemed adequate in all cases (Figure 8.6). This group was too small for any meaningful statistical analysis.



#### 8.3.4 COMPARISON OF THE CONSERVATIVE AND OPERATIVE GROUPS

We compared the conservative and operative groups with respect to the pain and work scores. The statistical program Statexact was used for this purpose. Three patients with unresolved complete paraplegia were excluded from this analysis. We found a significant difference in the pain score between the two groups in favor of the operative group (The Pearson's chi-square = 12.24 with 3 degrees of freedom; the exact  $p = 0.0037$ ).

Considering the work score we could not find a significant difference between the two groups (the Pearson's chi-square = 5.282 with 4 degrees of freedom; the exact  $p = 0.28$ ). Although in the operative group in comparison to the conservative group there was a shift to lower categories, the differences were not big enough to reach statistical significance with the numbers available.

#### 8.4 DISCUSSION

In this study we were able to create a cohort of patients with thoracolumbar spine fractures with adequately described lesions and treated according to a constant treatment protocol by a limited number of dedicated surgeons. To our knowledge this is the first prospective study using MRI to describe injury patterns in detail. Although the number of patients in the study with minimal 2 years follow up is not very large, even with this relatively small number we were able to find some interesting relations.

First of all, it is remarkable that we found a significant difference in the clinical outcome between the conservative and operative group even with our treatment protocol, which can not be called very conservative. Since the development of safe and effective operative alternatives for management of thoracolumbar spine fractures, the issue of the proper treatment of these patients has been heatedly debated. Radical proponents of non-operative treatment declare that almost all fractures can be treated conservatively with excellent outcomes (Shen 1999). But in all studies with a mixed group of operatively and conservatively treated patients, a more favorable outcome was found for the former group (Denis 1983/b, Gertzbein 1992). In the multi-center spine fracture study, the authors conclude: "On average, the surgical





patients had less pain at follow-up compared to the nonsurgical patients, although the difference was not statistically significant. On average, both the surgical and nonsurgical patients reported less pain at 2 years than at 1 year. In comparing the frequency of severe/moderate versus none/mild pain in the nonsurgical with the surgical group, there was an increased incidence of severe pain in those patients treated nonsurgically. This trend reached statistical significance at the 2-year evaluation point" (Gertzbein 1992). Our results at two-year follow-up confirm this difference. Of course ours is not a controlled study but the two groups in the cohort are comparable for many of the parameters if we exclude the paraplegics. If we can speak of a selection bias this is strongly against the operative group as more serious injuries were usually operated on. The significant difference in the pain outcome after two years confirms earlier reports that a subgroup of the conservatively treated patients suffers substantial persistent pain. Rather than categorically denying this fact, it would be much better to try to define the profile of patients with a high risk of developing persistent pain.

We detected some factors, which may be seen as risk factors for conservative treatment. Age seems to be a predictor of unfavorable outcome. Whether this is a result of poorer bone quality is not clear. The fact that the age limit lies around 30 years and that no difference was found between males and females speaks against this assumption. Another possible explanation might be a higher adaptability to changes and better means of functional compensation in younger patients. We also found a relation between progression of kyphosis and poor clinical outcome. Krompinger et al (1986) also reported increasing kyphotic deformity in some patients but could not relate this to poor outcome. In the multi-center spine fracture study (Gertzbein 1992), an increase of the average kyphosis angle from 12.4 degrees to 13.9 degrees was observed for the nonsurgical group. A positive relationship was also found between the amount of kyphotic deformity at 1 year and the amount of pain for all (surgical and nonsurgical) patients. In our study it seems that not the final deformity but rather the increase in the kyphosis angle is predictive of persistent pain. The question is whether this increase can be predicted from the beginning. Age also seems to be a significant factor for this para-



meter. We have shown that MRI can be helpful to develop radiological predictive criteria. The mechanism of increasing kyphosis seems to be a progressive settlement of the disc into the fractured endplate and vertebral body. The load-bearing capacity of the injured anterior column is thus the crucial factor. MRI parameters, which we used in this study, could predict this phenomena in most of the cases. A combination of endplate comminution in the anterior half and involvement of the vertebral body of more than one third as seen on MRI's was highly predictive of increasing kyphosis. Larger series using this categorization scheme may reveal the importance of some of the other parameters and increase the predictability of unsatisfactory clinical outcome of conservative treatment. Because in our study the MRI's were available to the surgeons who decided on the stability of the fracture, the role of other important parameters such as involvement of the posterior ligamentary complex may have been obscured.

With respect to the final work score of the patients the differences were not significant. But considering that almost two thirds of the patients in the operative group had some degree of neurologic involvement the two groups are difficult to compare for this parameter. Besides, the favorable social security environment in our country may blur some of the differences.

Although with our treatment protocol we were able to prevent serious complications such as progressive neurology or high degree of kyphosis progression in the conservatively treated group, we are unsatisfied by the high percentage of patients with residual persistent pain. In the 1993 AAOS monograph (Stauffer 1993) on the issue, the authors conclude (p. 60) that "it is anticipated that 80% of the (conservatively treated) patients will have some degree of complaint referable to the back". But nevertheless they state that the vast majority of these patients can be treated nonsurgically. Considering the safety and predictability of modern operative techniques we should ask what is an acceptable level of pain and discomfort after a spinal fracture. One "cultural" factor may be the high incidence of non-specific low back pain in industrial societies. This renders the physicians less receptive to back pain complaints after fractures. If the incidence of non-specific hip pain were as high as low back pain, development of effective treatment of femoral neck fractures might have been much more difficult.







Posterior stabilization and fusion with pedicle screw constructs was indeed an effective and reliable technique in this series in our hands. Some earlier studies reported high complication rates of this technique (McCormack 1994, McLain 1993 Speth 1995). Speth et al reported 17% failure of internal fixator construct in a multi-center study. This was a mixed series of patients treated by surgeons of varying experience. Our results are comparable to later reports with very low implant failure rates (Strømsøe 1997). We agree with Strømsøe et al that limitation of this surgical procedure to motivated and experienced surgeons will reduce complication rates. McCormack et al reported a 36% rate of screw breakage with VSP constructs. McLain et al reported implant failure in 56% of the CD implants. These rates are much higher than implant failures reported of the internal fixator (Crawford 1994, Dick 1987, Bednar 1992, Speth 1995, Strømsøe 1997). Short pedicle screws of VSP or CD type may be less suitable for posterior fixation of unstable fractures than the long Schanz screws, which allow purchase of the anterior cortex and provide a long lever arm. We could not find a relation between the load sharing classification of McCormack et al (1994) and complications or recurrence of kyphosis. This may be a result of the low incidence of material failure in our group and this load sharing classification scheme may have a predictive value in larger series.

Significant recurrence of the kyphotic deformity (10 degrees or more) was observed in 12 out of 28 patients treated with a posterior pedicle screw construct. Earlier observations (Oner 1998) in a retrospective series about the mechanism of this phenomenon are confirmed in our study. On mid-sagittal sections of the MRI's the geometry of the central depression of the endplate remained practically unchanged regardless of the amount of correction of the kyphosis angle or the wedge angle. One possible solution of this problem is transpedicular correction of the central impression followed by transpedicular grafting. One study showed this to be effective in reducing the amount of recurrence of kyphosis (Crawford 1994). Another study, in which transpedicular grafting alone was used without correction of the central endplate, showed no effect of this procedure on kyphosis recurrence (Speth 1995). Correction of the central deformity may be a crucial point for this technique. However, this is technically demanding,



and potentially serious complications have been reported (Sjöström 1995). Technical innovation may improve this technique. On the other hand, neither the recurrence of the kyphosis nor the final kyphotic deformity seems to have an influence on the clinical outcome after operative treatment. As Nicoll pointed out in 1949 “the important factor in determining function is stability between the damaged segments and not the position in which it is achieved”.

Earlier observations (Oner 1998) (Chapter 7) about the fate of the intervertebral disc are confirmed in this study. Changes in the disc space after posterior fixation are not a form of chronic instability but a redistribution of the disc tissue in the changed morphology of the disc space. Thus, discs provide stability to the damaged segment and attempts to remove the disc through a transpedicular approach will destabilize the injured segment and cause failure of fixation.

MRI parameters used in this study may also help predict kyphosis recurrence. Only one out of 11 patients without posterior ligamentary complex (PLC) involvement had 10 degrees of kyphosis recurrence while partial involvement of the PLC (states 2 or 3) as seen on MRI was highly correlated to significant kyphosis recurrence. This relation was not as evident with complete ruptures (PLC State 4). These three categories probably represent different injury mechanisms with different mechanical consequences. The mechanism of this partial PLC disruption leading to recurrent kyphosis is unclear, because posterior fixation is expected to neutralize the effects of this disruption. This involvement may be related to an unfavorable geometry of the endplate fracture leading to the kyphosis recurrence. These findings confirm earlier observations by McAfee et al (1983) who categorized these injuries into stable burst fractures, unstable burst fractures and flexion-distraction injuries. This distinction between stable and unstable burst fractures also corresponds to the difference between the A 3 and B 2 injury types of the AO classification scheme (Magerl 1994). Although the immediate mechanical stability is most compromised in the flexion-distraction injuries (PLC 4 in the MRI categorization) posterior surgery can effectively reduce and stabilize the injured segment. However, incomplete disruption (PLC 2 or 3) represents unstable burst fractures in which the posterior column has failed in compression, lateral flexion or rotation leading to a combined insta-





bility. While most of the complete disruptions of the PLC are readily discernible on plain radiograms and CT's, the partial involvement may be frequently missed. MRI helps to make this crucial distinction. Unrecognized partial PLC involvement may also be responsible for major complications of conservative treatment, although we cannot confirm this in our study because the MRI's were available to the surgeons who decided on the treatment.

Anxiety about the recurrence of kyphosis has led some to choose more aggressive approaches such as anterior or combined anterior-posterior stabilization techniques (Gertzbein 1988). But these techniques may cause higher morbidity and complications without an evident clinical benefit. According to a preliminary report of a multi-center survey about the operative treatment of these fractures in Germany, complication and revision rates were for posterior alone 4.2%, for anterior alone 10.8%, and for combined anterior-posterior 7.6%, although these differences were not statistically significant with the numbers available (Knop 1998).

We conclude that controversy around the proper treatment of the fractures of the thoracolumbar spine can be resolved by prospective studies with the modern means of distinction of the component parts of injuries with the help of MRI. We recommend the use of MRI for these injuries in prospective studies to develop prognostic criteria. This will help rationalize the decisions about treatment options.





**CONCLUSIONS AND DISCUSSION**

**CHAPTER 9**



## CONCLUSIONS AND DISCUSSION

As the historical overview demonstrates, the proper diagnosis and treatment of thoracolumbar spine fractures is still an unsolved problem (Chapters 1 and 2). Many schemes for classification of these injuries, which are supposed to be the guidelines for treatment, have been devised, discussed and rejected. Before the invention of reliable surgical techniques, the main discussion was centered on the questions of whether reduction with plaster cast was necessary or not, and how long the spine should be immobilized. After the development of safe surgical techniques, the discussion continued with regard to which types of injuries should be better treated operatively and what kind of approach should be used. At the end of the 20<sup>th</sup> century, no consensus has yet been achieved on these issues. The fate of a patient with an injured spine still depends on the “surgical-cultural” preferences of the hospital he or she happens to be brought to.

Our study about the diagnostic and prognostic parameters concerning these fractures shows that our means of distinction and prediction are not yet quite well developed, although we are probably getting better at their treatment. We can reach some conclusions from our particular study:

Classification of these injuries has been difficult. Tens of different schemes and their innumerable ‘modifications’ have been devised, used, and abandoned (Chapter 2). This is an indication that basic patterns concerning these injuries are difficult to recognize. But all these efforts helped to develop abstract concepts about the structure and stability of the injured spine. The classification scheme developed by Magerl et al (the AO classification) is the culmination of efforts to classify the injury patterns on radiograms, which began with Böhler. The authors of the scheme, stating that all the previous classifications added to the knowledge and understanding of spinal injuries while none can be considered all-encompassing, developed a comprehensive system in which each and every fracture could be classified at different levels according to direction of the injury creating force, pathomorphology, and severity of the resultant fracture. But this scheme is based on some assumptions about the state of non-osseous structures without the means of direct visualization. We showed that because of these difficulties the scheme is poorly reproducible, especially at the





highest level where the assumptions about the integrity of ligamentary structures are most important (Chapter 3). The AO classification should be seen as a last grand project of unification of all efforts in the 20<sup>th</sup> century to recognize patterns with imaging techniques incapable of direct visualization of soft tissue injuries.

Magnetic Resonance Imaging is a powerful new imaging modality that can directly visualize soft tissues as well as bone and bone marrow. It can be a useful tool to investigate the injuries of the thoracolumbar spine. But its use should first be justified by studies that prove that with the MRI “what you see is what you get”. The most reliable way of doing that is cadaver studies. One study (Kliewer 1993) showed that ligament injury associated with spinal fractures is reliably reproducible with MR imaging. We have shown with a similar study using a fracture model of fresh human cadavers that intervertebral disc and endplate injuries are also perfectly reproducible with MRI (Chapter 4). These studies established the MRI as a reliable and sensitive imaging technique capable of detection of different injury patterns to all structures that may have significant prognostic influence.

Categorization of the MRI findings on a large enough sample is necessary to understand the patterns of injury to different parts of the spine. We did that on MRI's of 100 fractures (Chapter 5). The states of the anterior longitudinal ligament (ALL), posterior longitudinal ligament (PLL), posterior ligamentary complex (PLC), intervertebral discs (DI), endplates (EP), and vertebral body (COR) were separately categorized. We have developed a scheme to categorize the MRI findings of these structures on a scale of 1 to 4 in which state 1 represents no or minor injury with no mechanical consequences and higher grades implying higher probability of mechanical impairment. We have observed a wide range of different combinations of various states of these parameters. Many of the parameters defined in this study may be just ‘background noise’ without any prognostic significance. But considering the confusion around the outcome of these injuries with conservative treatment or posterior reduction techniques it is possible that these parameters actually do have consequences in the real life. We tried to integrate these findings with the AO classification, which proved to be extremely difficult. We are not sure whether it is possible to redefine the AO classification with MRI



or the development of a new classification system based on MRI findings will be necessary.

Posterior reduction and stabilization techniques with pedicle screw devices have been the most popular operative treatment method during the last two decades of this century. One of the problems of these techniques is loss of reduction and hardware failure. In a group of patients treated with the internal fixator of Dick we observed that a disproportional decrease in the intervertebral disc height was responsible for this, rather than a loss of correction of the bony deformity (Chapter 6). This phenomenon, which was earlier observed after treatment with the Harrington device, was also associated with material failure in our series. It was not clear whether this decrease in the intervertebral height was a result of a frank disc degeneration process or not.

Changes in the disc space after fractures of the thoracolumbar spine have been attributed to a kind of posttraumatic disc degeneration comparable to the so-called 'degenerative disc disease'. This phenomenon has also been used as an argument for more aggressive anterior or circumferential operations. We have shown in a retrospective MRI study that in the majority of the cases the discs did not show signs of degeneration at all (Chapter 7). We classified the state of the post-traumatic disc space in six types. Some disc types were associated with progression of kyphosis in patients treated conservatively. In the patients treated by posterior reduction and fixation, recurrent kyphosis appeared to result from creeping of the disc in the central depression of the bony endplate rather than from disc degeneration. We conclude that changes in the disc space after posterior fixation should not be seen as a form of chronic instability but as a redistribution of the disc tissue in the changed morphology of the space after fractures of the endplate.

Development of prognostic parameters for the fractures of the thoracolumbar spine is only possible if we can create and follow up cohorts of patients with adequately described lesions. With the parameters we developed with the MRI findings of trauma and follow-up, we followed up a group of patients that were treated according to a protocol unchanged during the study period (Chapter 8). For the conservatively treated patients we have found that progression of kyphosis was







related to parameters on the injury MRI concerning the endplate and vertebral body involvement. Age older than 30 years and progression of kyphosis were predictive of substantial pain at follow up. We also found a significant difference in the pain scores between the operatively and conservatively treated patients in favor of the operative group. For the operatively treated group, we found a clear relationship between initial MRI findings concerning the state of the posterior ligamentary complex and the recurrence of the kyphosis. Partial involvement of the PLC was strongly correlated with the recurrence of kyphosis after hardware removal.

A classification of different injury patterns only makes sense if it helps us predict the final outcome better than a simple chance distribution. Recognition of some patterns of injury does not necessarily lead to a better understanding of the prognosis. Only if the observed patterns are shown to be related to certain outcome parameters can we speak of their prognostic significance. A classification scheme is actually a mental construct or a model of a complex phenomenon that is supposed to inform us about the severity of the injury and the possible consequences. This information should finally provide us with a reasonable estimation of the outcome of different treatment modalities. Creation of an abstract mental construct of a complex phenomenon is a difficult and complicated process. Two possible strategies can be used for this purpose:

- One is the “top-down” strategy, which tries to recognize the patterns in some images of the injury and construct from there on a mental picture of the “essence” of the injury. This strategy has led, in the thoracolumbar spine fractures, to the creation of the architectonic abstraction of “spinal columns”, which is supposed to provide information about the states of the lower-level structures, the components of the injured spine. This conceptualization, developed by Holdsworth (1963), based on the descriptive classification schemes of Böhler (1929) and Nicoll (1949), has been highly influential in shaping the approach to these injuries. Many variations on this theme have been developed, following different strategies of refinements of the “columns” or by adding more columns to the scheme. However, one should never forget that these



columns are mental constructs and do not correspond directly to any anatomical or biomechanical entity. This strategy is an “idealistic deduction”, which carries the danger of reification of the mental construct. The “column” becomes a “thing” that is superimposed on the reality in order to understand it. The result of this is that the mental construct, which has to be produced and reproduced each time by an observer in order to understand the injury, becomes a necessary component of the classification scheme. But reproduction of a mental construct is a highly subjective process, which makes the whole enterprise quite unstable and unreliable. In other words, one is never sure what others reconstruct in their minds as “columns”, this being highly dependent on the personal experience of the observer with this mental construct in particular and mental abstractions in general. Besides, this deductive strategy leads to a certain rigidity of the whole enterprise, in that revision of the scheme to make it more congruent with novel information from new observations, for example as a result of a new imaging technology or substantial changes in injury patterns, requires addition of new mental constructs, new columns, to the schemes. In short this strategy is not easily “evolvable” in accordance with new data.

→ Another strategy may be a “bottom-up” inductive process. In such a process, data is gathered about the states of individual clinical and radiological parameters. Then this data is used to investigate the prognostic significance of these individual parameters alone and in combination with each other. This process finally yields an information space of the various parameters together with their prognostic significance and their inter-parametric relations. At this stage, one can search in this particular information space for possible patterns in order to construct an abstract mental picture of the whole phenomenon through an algorithmic compression process. That means, one can look for an abbreviated representation of all relevant observations in a shorthand formula. Meaningful patterns are probably to be found in this information space rather than in the space of imaging. Such a strategy would yield an “evolv-





able” pattern recognition process in which on the hand of changes in the information space, the congruence of the shorthand formulas can be continuously tested and increased.

The development of the AO classification scheme has apparently been a mixture of these two strategies. Although there is emphasis on a detailed analysis of the component parts of an injured spine, the designers were still under the influence of a “top-down” strategy, which actually requires a pre-existent mental concept in order to make sense of these detailed analyses of the component parts. Besides there is no analysis of the prognostic significance of these observed patterns and no clear strategy about the evolution of the scheme departing from new data.

At this point a discussion of the standpoint of Burstein (1993) (Section 2.1) is necessary. Although his argumentation is a valuable contribution to the discussion of uncritical development and use of classification schemes in orthopedics, his “crude materialistic “ approach to the problem can lead to a devaluation of all attempts to create mental tools in order to understand and to exchange information about phenomena encountered in orthopedic practice. Burstein compares fracture classification schemes to “appliances and tools” manufactured to perform a task efficiently. Hence he argues that an orthopedic tool (a classification scheme) works only if it produces the same desired results, time after time, in the hands of anyone who is likely to use it. Therefore “to use this tool before its workability is proved is inappropriate”. Only if the tool has been shown to be functional, according to Burstein, one can go on to a next step to prove that it is useful in clinical studies in which the classification has been used as the basis for the choice of treatment. This is, in my opinion, a serious confusion of levels of abstraction. A mental tool is in no ways comparable to a “manufactured” tool, which is the material result of a deliberate design process to perform a specific task. In sharp contrast, a mental tool, in this sense, is an iconic representation process, which involves the active creation of a mental image based on the sensory data of a complex observed reality. In other words, the relation between the observed phenomenon and its mental image is a symbolic relation between the “signified” and the “signifier”. A mental picture is not a photographic picture but an active creation. Although the human



mind is very competent in producing these mental images of complex observed phenomena in order to navigate in the dangerous world around her, it is very well known that this process is always an approximation strongly biased by the purposes of the subject. The consequence of this is: a) this process cannot be perfectly repeatable by the same observer because it involves an active creation each time, under slightly different circumstances; and b) the workability (repeatability) of the mental image is not separable from its usefulness (predictive power) because human minds do not create mental imagery of complex phenomena without a purpose. Another point is that these mental images are also “social constructs”, created in an environment of incessant communication with other minds by way of this kind of symbolic imagery. That means that any classification scheme is also a “cultural” product, which is created in a social process of many interactions between different agents with various historical backgrounds. This introduces another important “noise” into the whole system, which makes a perfect inter-observer repeatability impossible. Disregarding these aspects of classification systems in orthopedic practice, as is done by Burstein, would raise unrealistic expectations and can eventually undermine all the collective efforts for the creation of predictive tools. The most important property of a classification scheme is not its repeatability and usefulness, defined once and forever, but its capacity to evolve into forms with increasing repeatability and increasing predictive power during an active process of assessment, reassessment and refinement by as many participants of the field as possible.

In the light of these arguments, we propose to follow a “bottom-up” strategy in order to develop an “evolvable” process of thoracolumbar spine fracture classification, which can lead to an increasing predictive power of our mental pictures of these injuries with an increasing repeatability. Our study can become a starting point of such a process. We called the MRI findings described in this study (Chapter 5) “categories of states” because they actually represent a list of observational data. They constitute a subset of the vast space of all things knowable about a patient with a broken spine. The choice for this particular subset is only justified if they in some way relate to a future event, such as final deformity, patient satisfaction etc., which





may be interesting for our purposes of predicting the final outcome. A prospective study on a sizable sample (Chapter 8) shows that at least some of these parameters alone or in combination with each other may fulfill this criteria. Some (Flanders 1999) would say that this would be sufficient. But a real understanding of a phenomenon, which is necessary for the development of a predictive tool, requires a further conceptualization, i.e. a classification scheme. An abstract conceptualization is the creation of a model. In such a process we enter the design space with its own requirements and problems. From this particular subset of observational data, that is MRI findings and some clinical parameters such as age, sex, neurologic status, it is possible to create a limited, but nevertheless a vast number of models. These models can then be tested for their repeatability and their predictive power in order to find out the best model with the available data. It may be possible to use an existing elaborate scheme, such as the AO classification, as a starting point for the development of a model. “Tinkering” may be a better strategy than the development of a whole new scheme.

Such a “bottom-up” strategy, of course, requires a vast amount of raw data in order to create schemes with the requested qualifications. Only multicenter prospective studies with standardized data acquisition protocols can achieve this. Therefore, our study should be seen as an exercise in 21<sup>st</sup> century methodology rather than a definitive solution to diagnostic and prognostic problems associated with thoracolumbar spine fractures.





**SAMENVATTING EN CONCLUSIES**



**CHAPTER 10**

## SAMENVATTING EN CONCLUSIES

De juiste diagnose, classificatie en behandeling van thoracolumbale wervelfracturen blijven een problematisch en controversieel onderwerp in traumatologie. Een kort historisch overzicht (Hoofdstuk 1) laat zien dat de diagnose en behandeling van deze letsels vaak hebben geleid tot hevige discussies en onenigheden. Voordat veilige en effectieve chirurgische technieken waren ontwikkeld, lag het centrum van de discussie in de vragen of een poging tot gesloten repositie iets toevoegde en hoe lang de rug geïmmobiliseerd moest worden. De huidige discussie wordt gedomineerd door de vraag welke letsels met welke benadering operatief behandeld dienen te worden. Geen consensus is nog bereikt over deze vragen aan het eind van de twintigste eeuw. Het lot van een patiënt met een gebroken rug hangt nog steeds af van de “chirurgisch-culturele” voorkeuren van de kliniek waar de patiënt terechtkomt.

Onze studie over de diagnostische en prognostische parameters betreffende deze letsels laat zien dat onze middelen voor onderscheid van verschillende soorten letsels en onze schattingen van de prognose nog niet voldoende zijn ontwikkeld, hoewel wij waarschijnlijk vooruitgang hebben geboekt in de behandeling van deze fracturen en hun gevolgen.

Classificatie van deze letsels is altijd moeilijk geweest (Hoofdstuk 2). Tientallen schema's en ontelbare “modificaties” van deze schema's zijn ontwikkeld, gebruikt en verworpen. Dit is een aanwijzing dat de fundamentele patronen van deze letsels moeilijk te herkennen zijn. Alle inspanningen echter hebben bijgedragen tot de ontwikkeling van abstracte concepten over de structuur en stabiliteit van een gebroken rug. Het AO classificatie schema ontwikkeld door Magerl et al (1994) is de culminatie van alle inspanningen sinds Böhler om deze letsels te classificeren op basis van conventionele beeldvormende technieken. Deze auteurs constateerden dat al de voorafgaande classificaties hebben bijgedragen aan onze kennis en begrip van deze letsels, hoewel geen enkele schema gezien kan worden als een alles-omvattende conceptualisatie. Zij ontwikkelden een “comprehensief systeem” waarmee elke letsel ingedeeld kan worden op verschillende niveau's volgens de richting van de trauma krachten, pathomorphologie en de ernst van de resulterende fractuur. Maar dit schema is gebaseerd op







veronderstellingen over de toestand van niet-benige structuren zonder de middelen voor een directe beeldvorming. Wij hebben aangetoond (Hoofdstuk 3) dat vanwege deze moeilijkheden de reproduceerbaarheid van dit schema te wensen over laat vooral op de hoogste laag waar de integriteit van deze structuren de belangrijkste factor is. De AO classificatie dient gezien te worden als de laatste poging van unificatie van alle inspanningen in de twintigste eeuw voor herkenning van letselpatronen met beeldvormende technieken die geen direct beeld kunnen geven van de omvang van niet-benige letsels.

Magnetic Resonance Imaging (MRI), is een krachtige nieuwe beeldvormende techniek waarmee zowel het bot en het beenmerg als de weke delen van een gebroken rug gevisualiseerd kunnen worden. MRI kan zich bewijzen als een waardevol instrument voor onderzoek van deze complexe letsels, maar allereerst moet worden aangetoond dat de MRI beelden kloppen met de werkelijkheid. Vergelijkende kadaver studies zijn hiervoor de meest geschikte methode. In een eerdere studie (Kliwer 1993) is aangetoond dat ligamentaire letsels, gepaard gaande met wervelfracturen, betrouwbaar afgebeeld kunnen worden met MRI. In een vergelijkbare studie, gebruik makend van een model met verse humane kadavers, hebben wij aangetoond (Hoofdstuk 4) dat ook de letsels van de dekplaat en tussenwervelschijf goed afgebeeld worden met behulp van MRI technieken. Deze studies bevestigen de MRI als een betrouwbare en sensitieve beeldvormende techniek die in staat is alle structuren betrokken in een letsel met een mogelijke prognostische waarde voldoende af te beelden.

Categorisatie van MRI bevindingen in een adequate populatie is noodzakelijk om de letselpatronen te kunnen herkennen. Wij hebben een categorisatieschema ontwikkeld op basis van de MRI's van 100 fracturen (Hoofdstuk 5). De toestand, "States" van anterieure longitudinale ligament (ALL), posterieure longitudinale ligament (PLL), posterieure ligamentaire complex (PLC), intervertebrale discs (DI), dek- en sluitplaten (EP) en wervellichaam (COR) zijn separaat bestudeerd. Een schema is ontwikkeld om de MRI bevindingen van deze structuren te categoriseren op een schaal van 1 tot 4. State 1 vertegenwoordigt geen of minimaal letsel van de betrokken structuur zonder mechanische consequenties terwijl hogere "States" een oplopende waarschijnlijkheid van mechanische verzwakking aangeven. Een



grote verscheidenheid van combinaties van verschillende “States” van deze structuren zijn waargenomen. Veel van de parameters gedefinieerd in deze studie zijn wellicht niet meer dan achtergrondgeruis zonder prognostische waarde. Maar aangezien er grote verwarring heerst over de uitkomsten van deze letsels na conservatieve behandeling of posterieure repositie en fixatietechnieken, is de kans groot dat sommige van deze parameters belangrijke consequenties hebben. Onze pogingen deze parameters te integreren in het AO schema leidden tot moeilijkheden. Het is niet duidelijk of de AO classificatie opnieuw gedefinieerd kan worden aan de hand van deze parameters danwel dat nieuwe schema's op basis van MRI bevindingen noodzakelijk zullen zijn.

Posterieure repositie en fixatie met behulp van pedikelschroefimplantaten is de meest gangbare operatietechniek van de laatste twee decennia geweest. Een van de problemen van deze techniek is implantaatbreuk en verlies van repositie. In een groep patiënten behandeld met de interne fixateur van Dick, hebben wij waargenomen dat een disproporioneel verlies in de intervertebrale ruimte verantwoordelijk was voor dit fenomeen en niet het repositieverlies van benige correctie (Hoofdstuk 6). Dit fenomeen, dat in het verleden ook waargenomen was in fracturen die waren behandeld met een Harrington implantaat, was ook in onze serie gerelateerd aan implantaatbreuk. Het was niet duidelijk of dit hoogteverlies in de intervertebraleruimte een gevolg was van een echte discusdegeneratie.

Veranderingen in de intervertebrale ruimte na doorgemaakte thoracolumbale fracturen zijn in het verleden gezien als een soort post-traumatische discusdegeneratie, vergelijkbaar met de zogenaamde “degeneratieve discus ziekte”. Dit fenomeen werd ook vaak gebruikt als een argument voor aggressievere anterieure of circumferentiele operatietechnieken. In een retrospectieve MRI studie (Hoofdstuk 7) hebben wij echter aangetoond dat in de grote meerderheid van de gevallen geen aanwijzingen zijn gevonden voor een discusdegeneratie. Een classificatieschema van de post-traumatische discusruimte is ontwikkeld met 6 verschillende types. Sommigen van deze discustypes zijn gerelateerd aan toename van kyphose in conservatief behandelde patiënten. In de patiënten die waren behandeld met een posterieure fixatie, was de terugval in de kyphosecorrectie het gevolg van kruipen





van de discus weefsel in de centrale depressie van de gebroken dekplaat, en niet het gevolg van een echte discusdegeneratie. Wij concluderen derhalve dat de veranderingen in de discusruimte na een fractuur niet gezien dienen te worden als een vorm van chronische instabiliteit maar als een redistributie van het discusweefsel in de veranderde morfologie van de dekplaat.

Het ontwikkelen van prognostische parameters van thoracolumbale wervelfracturen is alleen mogelijk als men een cohort van patiënten kan samenstellen met een adequaat beschreven letsel en een voldoende follow-up. Met de parameters van MRI bevindingen zoals beschreven in hoofdstuk 5 werd een groep patiënten die was behandeld volgens een vast protocol vervolgd (Hoofdstuk 8). Bij de conservatief behandelde patiënten is gebleken dat toename van de kyphose voorspeld kon worden met behulp van MRI parameters betreffende dekplaat en wervellichaam betrokkenheid. Leeftijd boven 30 jaar en toename van kyphose voorspelden een substantiële, persisterende pijn twee jaar na het ongeval. Twee jaar na het ongeval bleek er een significant verschil in de pijnscores van de conservatief en operatief behandelde patiënten te zijn ten gunste van de operatief behandelde patiënten. Voor de geopereerde groep, werd een evidente relatie gevonden tussen de MRI parameters betreffende de betrokkenheid van het posterieure ligamentaire complex (PLC) en een terugval in de kyphose correctie. Partiële letsels van de PLC voorspelden een significante terugval in de kyphosecorrectie.

Concluderend kunnen wij vaststellen dat de controverse over de classificatie en behandeling van thoracolumbale wervelfracturen het gevolg is van onvoldoende middelen om alle betrokken delen van een gebroken rug in kaart te brengen. De ontwikkeling van classificatieschema's met voldoende voorspellende waarde is wellicht mogelijk met behulp van MRI bevindingen in combinatie met klinische gegevens van de patiënten. Hiervoor echter zijn prospectieve multi-center studies noodzakelijk om grote hoeveelheden data te creëren zodat men de patronen kan herkennen die een betrouwbare voorspelling mogelijk maken. In onze studie zijn de hiervoor benodigde instrumenten ontwikkeld.





## EPILOGUE



## EPILOGUE

*I have yet to see a problem, however complicated, which when you looked at it in the right way, did not become still more complicated.*

Paul Anderson

Exactly one hundred and one years ago, the first radiogram of the spine appeared in the literature, coincidentally in a book about thoracolumbar spine fractures (Wagner 1898). Successful imaging of fractured vertebrae is also first mentioned in this book. Since then the matter seems only to have become more and more complicated. Before the invention of imaging techniques, only fractures and dislocations with a gross deformity could be recognized as such. Successful imaging of the bony vertebrae opened the way for the recognition of different patterns of injury. About 30 years later, the first conceptualization of a spine fracture classification appeared in the literature (Böhler 1929). Subsequently, other investigators in the field tried to develop schemes, which, beginning from the pattern recognition process would eventually say something about the future of the injured spine. All this has led to an increasing complexity of the field. Those who had hoped that advancements in the imaging techniques would facilitate this process must have felt betrayed by the proliferation of schemes crowding our literature lists and driving our residents to despair. It is time to take a break and to discuss the theoretical base of this process.

The goal of science is to make sense of the diversity of phenomena around us. This goal is actually not much different than the usual way human brains work. To make sense of nature means to make predictions about what will happen next. As Dennet (1996) puts it “the purpose of brains is to create futures”. Scientific method is only a formalization of our brain processes. But this formalization creates a powerful human machine in that it can incorporate many brains in this process of “creating futures” across borders and across generations. Scientific method begins with gathering information about the world through observation, with the final aim of testing predictions about how the world will react to changing circumstances. Between this initial and final aim lies the motor of the scientific process.





Observational data alone is actually nothing else than a long list of “what is going on out there”. The main task of science is the transformation of these lists of observational data into abbreviated forms by recognition of patterns. The recognition of these patterns allows the information content of the observed events to be replaced by a shorthand formula, which supposedly has the same or nearly the same information content. If any sequence of events can be given an abbreviated representation of this list of observations, then this sequence is called “algorithmically compressible”. In general the shorter the possible representation of a sequence of observations, the less random it is. If there is no possible way of expressing a sequence of observational data in an abbreviated representation, then these events are totally random. If we follow this argument, we can see the scientific enterprise as a search for algorithmic compressions. We first list sequences of observed data; then we try to formulate ways of compression that can compactly represent the information content of these sequences; and then we test the correctness of our algorithmic compressions to predict the next events in the sequence. Without the development of these algorithmic compressions, all science would be a mindless collection of every available observation.

However, if we try to apply this nice, neat, and naïve notion of science to our specific field of thoracolumbar fractures, some serious complications arise. Some of these problems are:

- If there are rival systems of algorithmic compression how can one decide which is the best one? Theoretically, the system, which can produce the shortest formulation with the lowest loss of information content, would be preferable. However, our list of observational data is not completely independent of the “next events” we want to predict. In other words, if we want to predict, for example, the final kyphosis angle, the information content of our observational data may not coincide with the set of data when we want to predict the final “patient satisfaction”. And still worse, these two sets of observational data may not be equally compressible with the same algorithm.
- The brain is the most powerful algorithmic compression machine that we know of. It reduces complex sequences of



sense data to simple abbreviated forms of mental representations. However, our brain is a result of an evolutionary process “red in tooth and claw” in which the only thing that matters is whether a mechanism helps the survival of the organism involved or not. The consequence of that is that the algorithmic compression machines of our brains may be biased in ways, which we are not even aware of.

- Another problem is that this pattern recognition apparatus may work sometimes too well. It is known that our brains tend to see patterns where there can be no patterns. The most famous example of this phenomena is the so called “gambler’s fallacy”. A gambler can ruin himself by the idea that he sees a certain pattern in a roulette machine, such as “three times red is followed by five times black” etc, even if he knows that the probability of getting red or black must be exactly the same each time. Are there really understandable patterns in thoracolumbar fractures or are we just making it up?
- This scientific method has been so successful in the explanation of the physical world around us, that the style of conventional physics has become a kind of standard for all scientific discourse. The perfectly symmetrical world of a Newtonian universe in which a plethora of observations about masses and planets etc. can be algorithmically compressed into a handful of laws of gravity, perfectly capable of predicting all events, seems to have set the standard in our minds about how “real” science should work. Although this picture of a perfect Newtonian universe has long been abandoned in the real science of physics, this metaphor keeps exerting a powerful influence on our minds. But the kind of data we are dealing with is probably not so easily compressible at all for reasons I will discuss.

Actually, the clinical sciences may have more common ground with the science of meteorology than with Newtonian physics. Like the meteorologists, we, in the clinical sciences, deal with complex systems governed by the rules of chaos. Our territory must be included into the domain of the emerging “science of complexity”. We have to learn to think in terms of probabilities, expectations, strange attractors,







sensitivity to initial conditions etc, etc. Why? Let us examine the example of the study object of this thesis. The study object is a system composed of:

- A human being as patient
- Forces of trauma
- Methods of visualization of the resultant injury
- Systems of classification of these injuries that have been devised before
- A radiologist and a surgeon deciding on the classification of the injury
- The surgeon deciding on the treatment options about this specific patient
- The surgeon treating this patient
- Measurement of the outcome of the treatment.

All of these elements are horribly complex systems in themselves and now they interact with each other, too. And we expect to predict the outcome of such a complex interaction? The system is “sensitive to initial conditions” in many ways, and these initial conditions are innumerable. For example: the social and work status of the patient, the quality of his/her bones, the mood of the software deities of the imaging machines at that moment, the degree of awareness of the radiologist of the theoretical constructs about this kind of injury, whether the surgeon had enough coffee that particular morning, the IQ of the patient, the IQ of the surgeon, whether the operating nurse is suffering a dreadful headache because of the wine she drank the evening before, whether the patient just had a terrible quarrel with the partner the day you happen to want to measure the patient satisfaction etc, etc, etc. Add to that the fact that all of these elements are constantly changing. The patterns of injury, the capability of visualization, the experience of the surgeon, the expectations of the patient, the salary of the radiologist etc, etc, etc. This is worse than the worst nightmare of a meteorologist who is trying to predict whether it is going to rain the next day. Worse than that, the meteorologist in our example is also allowed to fiddle with clouds and thunders and ionosphere and then is expected to predict not only the rain but also whether the people for whom he is forecasting will like the rain at that particular moment.



What is an acceptable outcome of this whole process anyway? We are not in the fortunate position of, say, a clinical oncologist for whom the outcome of any treatment can be simply measured with the knowledge of whether the patient is dead or alive. The patient population of Nicoll, in the 1930's and 1940's in the coalmines of the United Kingdom could go back to the mines although 60% of them had substantial pain. Is it realistic to expect that the patients in the industrialized societies at the end of the century behave the same way? Why should we accept a higher degree of pain and disablement by the patients with thoracolumbar spine fractures than, say, patients with a fracture of the long bones? What is an acceptable degree of discomfort after a thoracolumbar spine fracture in the first decades of the 21st century in the highly competitive industrial societies where people are expected to be more than 100% healthy if they want to be eligible for any work at all? What is a good clinical outcome after a fracture without neurological involvement or with partial neurological loss of function?

Should we despair? Should we say as in the last item in one version of the "Murphy's Laws of Perversity": Mother Nature is a witch! Should we say "do whatever you find appropriate and then go pray for the mercy of the spine gods"? I think not. Rather, we should think about our aims and methods. We should accept that we have only statistical truths about the matter; that we can only make predictions of some not quite high percentages at this moment; that our means of pattern recognition in traumatology are not highly developed; that we probably do not agree with each other well; that we all make wrong decisions quite often. But we should not lose sight of our concrete aim: to develop instruments of communication and education, which can assure that more and more surgeons more and more often make the right decisions so that our patients will end up less disabled and less unhappy. That the Frida's of the 21st century can lead lives free of constant pain and suffering.



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## CURRICULUM VITAE

The author of this thesis was born in September 11, 1956 in Kars, Turkey. After his graduation from the Istanbul American Robert College in 1974, he went to Ankara to study medicine at the Hacettepe Medical School. He graduated in 1980 and began his residence training at the Department of Orthopedics and Traumatology of the University Hospital Hacettepe in Ankara. A couple of months after the military coup of 12 September 1980, he was arrested by the military on charges of medical assistance to fugitive opponents of the military regime. After his release in 1983, he was forced to leave the country and came in 1984 to the Netherlands. With the help of the Erasmus University Rotterdam and the UAF (University Assistance Funds) he got a position as non-training resident in 1985-86 at the Department of Orthopedic Surgery of the University Hospital Rotterdam by Prof. Dr. B. van Linge. In 1987 he started his training in general surgery at the Sint Franciscus Gasthuis Rotterdam (Head Dr. C.H.J. Stockman †, later Dr. J.C.J. Wereldsma), followed by orthopedic surgery training at the University Hospital Rotterdam (Head Prof. Dr. B. van Linge, later Dr. A.F.M. Diepstraten) and peripheral training at the Leyenburg Hospital in the Hague (Head Dr. P.J. Moll, later Dr. A.J.M. Sauter). Since November 1993 he is a staff member at the Department of Orthopedic Surgery of the University Medical Center Utrecht (Head Prof. Dr. A.J. Verbout).





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